# The Multiple Dimensions of Mental Representation in Face Recognition

Thesis presented to the Faculty of Arts of the
University of Zurich for the degree of
Doctor of Philosophy

by

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Accepted in the spring semester 2010 on the recommendation of
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Zurich, 2010

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## 1 Summary

Face recognition is one of the most remarkable abilities that humans exhibit, especially considering the fact that all human faces possess highly similar visual patterns, being composed of relatively few constituent elements in an identical configuration. Although faces contain complex information, such as gender, age, race, emotion, attractiveness, etc., humans are able to decode the multiple facial information exceedingly rapidly. The processing can even occur before paying attention to them (Reddy, Wilken, & Koch, 2004; Reinitz, Morrissey, & Demb, 1994). Face recognition is demonstrated very early after birth (Goren, Sarty & Wu, 1975, Johnson, Dziurawiec, Ellis & Morton, 1991; Mondloch, Lewis, Budreau, Maurer, Dannemiller, Stephens, & Kleiner-Gathercoa, 1999; Acerra, Burnod, & de Schonen, 2002).

A widely known phenomenon concerning face recognition is the *face inversion effect* (FIE), which refers to the fact that the recognition of faces is disproportionately impaired by inversion when compared to the recognition of other mono-oriented objects such as airplanes and houses (Yin, 1969, 1970; Valentine, 1988; Searcy & Bartlett, 1996; Freire, Lee, & Symons, 2000; Schwaninger & Mast, 2005). The occurrence of FIE is considered as important evidence to support the notion that the mechanism of face recognition is different from that of object recognition. In the domain of face recognition research, three kinds of distinct processing have been thoroughly investigated that collectively would define the ability of face recognition (Mondloch, Grand, & Maurer, 2002). First, featural or component processing refers to an analytic process of decomposing a face into a set of internal features (Sergent, 1984; Freire et al., 2000; Freire & Lee, 2001; Hayward, Rhodes, & Schwaninger, 2008). Second, configural processing refers to the coding of a spatial relationship among facial features (Bruce, Doyle, Dench, &

Burton, 1991; Rhodes, Brake, & Atkinson, 1993; Freire et al, 2000; Schwaninger, Lobmaier, & Collishaw, 2002; Mondloch et al., 2002; Schwaninger, Ryf, & Hofer, 2003; Rhodes, Hayward, & Winkler, 2006; Hayward et al., 2008; Schwaninger, Lobmaier, Wallraven, & Collishaw, 2009). Third, holistic processing refers to treating faces as a gestalt regardless of the basis comprising the whole (Young, Hellawell, & Hay, 1987; Hole, 1994; Tanaka & Farah, 1993; Richler, Gauthier, Wenger, & Palmeri, 2008). Schwaninger and his colleagues (Schwaninger et al., 2002; Schwaninger, Wallraven, & Bülthoff, 2004; Wallraven, Schwaninger, & Bülthoff, 2005; Schwaninger et al., 2009) propose a computational model of face representation. They suggest that featural and configural informations are represented separately in the early stage of face recognition. Afterwards, these two kinds of representations were integrated to a holistic face representation. As shown in a set of different studies, this model could explain various aspects of human face recognition such as processing featural and configural information (Schwaninger et al., 2004; Wallraven, et al., 2005) as well as specific effects of viewpoint (Wallraven, Schwaninger, Schuhmacher, & Bülthoff, 2002).

Considerable evidence suggests that face configural encoding might be the major contributor for the occurrence of the FIE (Diamond & Carey, 1986; Bartlett & Searcy, 1993; Rhodes, Brake, & Atkinson, 1993; Tanaka & Farah, 1993; Searcy & Bartlett, 1996; Tanaka & Sengco, 1997; Leder & Bruce, 1998, 2000; Schwaninger & Mast, 2005 ). Freire, Lee, and Symons (2000) required participants to discriminate faces differing either in facial features or in the relations among the features. The FIE was observed only in the latter condition, suggesting that participants were unable to successfully retrieve the configural information in the recognition of  inverted faces. Schwaninger and Mast (2005) manipulated the degree of rotation for configural and featural alteration and found that the FIE was demonstrated only for featural alterations but not for component alterations. In addition, they found that the FIE is especially significant when the faces were rotated for $90^0$ and $120^0$ instead of $180^0$ when the faces were entirely inverted. Murray, Yong, and Gillian (2000) provided another piece of evidence for the FIE from rating faces for bizarreness. They found that bizarreness rating shows discontinuity for Thatcherized faces (Thompson, 1980) and configuration distortion, but not for featural distortion. Their results suggest a qualitative difference between the processing of upright and inverted faces. Specifically, for inverted faces, the encoding of configural information was impaired disproportionately comparing to the encoding of feature information. A shift in the processing mode (i.e., from configural to featural processing) could be observed based on the discontinuity of rating when faces were rotated for about $90^o$ and $120^o$. This finding is accordance with the findings of Schwaninger and Mast (2005). Apparently, the incomparable proficiency in configural encoding between upright and inverted faces results in the occurrence of the FIE. However, following research revealed that the FIE was not restricted to the face identification but can also be found in gaze perception (Schwaninger, Lobmaier, & Fischer, 2005). However, Schwaninger et al. (2005) found that the inversion effect found in gaze perception is mainly due to the featural information.

The FIE implies that face recognition might employ a special mechanism different from that of object recognition (Yin, 1970). In addition, it has been observed that face recognition is mediated by a specialized cortical mechanism (Fusiform Face Area, FFA) (Kanwisher, McDermott & Chun, 1997). Some researchers claim that face perception is special, and that holistic and configural processing are innate properties of face perception (McKone, Kanwisher, & Duchaine, 2007; Mckone & Robbins, 2007). However, this argument is challenged by other researchers. Gauthier and her colleagues found that humans also exhibit the inversion effect in the recognition of nonface objects when they become experts for those objects, such as car, bird, Greeble, or Ziggerin (Gauthier, Curran, Curby, & Collins, 2003; Gauthier & Tarr, 1997; 2002; Wong, Palmeri, & Gauthier, 2009). Greebles and Ziggerins are artificial objects composed of different volumetric parts. It requires subordinate-level expertise to distinguish the individual Greeble or Ziggerin among the Greeble or Ziggerin families. Gauthier et al. propose an expertise hypothesis to explain the particular role of configural and holistic processing in face recognition. They claim that holistic and configural processing can be learned through expertise in discriminating subordinate-level differences between individuals within a category (Gauthier & Tarr, 2002; Wong et al., 2009).

Another widely known hallmark of face recognition is the ‘own-race advantage’ also termed the ‘other-race effect’. Accumulating evidence indicates that it is easier for people to recognize the faces of their own race than of other races (Rhodes, Tan, Brake, & Taylor, 1989; Tanaka, Kiefer, & Bukach, 2004; Michael, Caldara, & Rossion, 2006; Hayward et al., 2008, see Meissner & Brigham, 2001 for a review). Goldstein (1979A; 1979B) indicated that the own-race advantage is perceptual rather than physiognomic. He analyzed research concerning physical anthropological measures of faces from Japanese, Whites, and Blacks and found no evidence for racial difference in facial heterogeneity. Evidence suggests that the own-race advantage might be due to an impairment in extracting the feature information, holistic information, and configural information in other-race faces (Michel et al., 2006; Rhodes et al., 2006; Hayward et al., 2008).

Although humans are able to process faces exceedingly early in life (Goren et al., 1975, Johnson et al., 1991; Bhatt, Bertin, Hayden, & Reed, 2005), this ability remains immature and continues to improve throughout childhood. It takes more than a decade for a child to reach the adult’s level of face recognition expertise

(Feinman, & Entwisle, 1976; Carey, 1992; Itier & Taylor, 2004a, 2004b; for a review see Chung & Thomson, 1995, and McKone, Crookes, & Kanwisher, in press). The developmental courses of the three different types of face processing mentioned previously have been found to be asynchronous. Feature and holistic processing develop faster than configural processing (Carey & Diamond, 1977, 1994; Freire & Lee, 2001; Mondloch et al., 2002; Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998; Itier & Taylor, 2004b).

Considerable research suggests that the processing of familiar and unfamiliar faces involves different mechanisms. The internal and external facial features in faces are processed to a different extent in familiar and unfamiliar faces. Familiar faces are more readily recognized from their internal than from their external features, whereas unfamiliar faces are equally recognized from their internal and external features (Ellis, Shepherd, & Davies, 1979; Young, Hay, McWeeny, Flude, & Ellis, 1985; Bonner, Burton, & Bruce, 2003). Moreover, familiar faces are coded mainly by the configural information, while unfamiliar faces are coded mainly by the featural information (Peirce, Leigh, & Kendrick, 2000; Veres-Injac & Persike, 2009). The differences between the processing of familiar and unfamiliar faces are also demonstrated in psychophysics, physiological, and neurophysiological research. Recognition of familiar faces not only reduces the activation of the FFA (Kanwisher, McDermott, & Chun, 1997), but also attenuates activation of the amygdala (Hart et al, 2000; Schwartz et al, 2003). Even in familiar faces, the neural responses are also different among recognitions of self face, family members, personally familiar faces, and famous familiar faces (Sugiura et al., 2005; Platek et al., 2006; Gobbini & Haxby, 2006; 2007; Devue et al, 2007; Platek & Kemp, 2009). It has also been found that some patients with brain lesions are impaired in the recognition of familiar faces but intact in the recognition of unfamiliar faces or vice versa. These findings imply that the processing of familiar and unfamiliar faces might be mutual dissociable (Warrington & James, 1967; Benton, 1980; Malone, Morris, Kay, & Levin, 1982).

Although face recognition research draws forth many diverse issues, all these issues involve a conjoint fundamental question concerning how the face is represented in the human brain. This dissertation investigates this topic of face representations hierarchically from the following three major sections in four studies with nine experiments:

1. Three-dimensional (3D) visual representation in face recognition;
2. Two-dimensional (2D) visual representation in face recognition;
3. One-dimensional (1D) visual representation in face recognition.

In addition to the discussion of face representation, this dissertation also examines spatial representation in the fourth section with a short experiment.

There has been a long debate on whether or not humans construct 3D representations of objects. This debate arises mainly from the very beginning process of the human vision system, where images are cast onto the retina as two-dimensional. However, humans readily perceive the external world in a 3D stereoscopic format. Accordingly, whether or not humans can have a 3D representation of objects and faces remains debatable. Marr suggests that the object is represented originally from the 2D (retina) to edges and primitives (raw primal sketch) stage. Afterwards, a 2 ½ (surface) representation is formed. Then, in the final stage, a 3D representation is final constructed (Marr, 1976; Marr & Nishihara, 1978). Biederman further proposed the Recognition by Components (RBC) theory to explain the process of 3D perception (Biederman, 1987; 2000). He claims that object recognition is based on structural descriptions which specify an object by its constituent parts, e.g. Geons and their spatial relations (Geon Structural Descriptions, GSD). These arguments are generally considered as object-centered theories. By contrast, view-based theories argue that objects are not stored as object-centered structural descriptions but as a collection of 2D views (Bülthoff & Edelman, 1992; Tarr & Pinker, 1989; Tarr & Bülthoff, 1995; Biederman & Kalocsai, 1997; Bülthoff, Edelman, & Tarr, 1995). Object recognition relies on matching a novel view of an object to the stored views by using different mechanisms, such as linear interpolation between views (Poggio & Edelman, 1990), multiple views plus transformations (Tarr & Pinker, 1989), or linear combination of views (Ullman & Basri, 1991).

In contrast to the debate on 2D versus 3D representation in object recognition, it is generally assumed that faces are represented by a collection of 2D views (Biederman & Kalocsai, 1997; Bülthoff, Edelman, & Tarr, 1995; Wallraven, Schwaninger, Schuhmacher, & Bülthoff, 2002). However, much evidence implies the existence and application of 3D representation in face recognition. The evidence comes from at least three different research lines, such as research regarding the recognition of one's own profile, haptic face recognition, and brain neuron activation. In Study 1, with six experiments, I discuss the related references elaborately and examine whether or not humans sculpt 3D face representation in the cognition system. A new paradigm which requires participants to match a one-tone black silhouette to its frontal-view face is adopted to examine the application of 3D representation in face recognition. The issue of 3D face representation is further extended in Study 2 to examine the development of 3D representation in face recognition. In Study 2, children with immature face recognition ability were recruited to examine the proficiency of 3D face representation.

In the second section of this dissertation, face recognition is investigated from the aspect of 2D representation, i.e. in the planar level of visual representation. Face representation in two-dimension is investigated from the hallmark of face recognition, the face inversion effect (FIE). Generally, the FIE can easily be replicated in face recognition research and has been widely adopted as an essential index for examining different issues in face recognition research, such as the differences between object vs. face recognition (Yin, 1970; Tanaka & Farah, 1993; Farah, Drain, & Tanaka, 1995; Farah, Wilson, Drain, & Tanaka,1995), feature vs. configural processing (Freire, Lee, & Symons, 2000; Goffaux, Hault, Michel, Vuong, & Rossion, 2005; Goffauf & Rossion, 2007), own race vs. other race processing (Rhode et al., 1989; Rhode et al., 2006), high vs. low spatial frequence in face recognition (Goffaux et al., 2005; Goffaux & Rossion, 2006), and the development difference of face recognition (Mondloch et al, 2002; Itier & Taylor, 2004a, 2004b). However, the factors that mediate the fluctuation of FIE are rarely explored. In most of the existing studies, analyses were conducted just to demonstrate whether or not the FIE was observed in a particular condition, or whether or not the FIE was equal under different conditions. The factors that might affect the emergence or magnitude of the FIE have mostly remained beyond examination. This issue is investigated in the second section of this dissertation by means of manipulating the ratio of configural alteration. In Study 3, the configural information was manipulated parametrically in six different ratios, ranging from 4% to 24%. Participants were required to judge whether a pair of faces were entirely identical or different. The paired faces to be compared were presented either simultaneously (Experiment 5) or sequentially (Experiment 6). The fluctuation of the FIE under different ratios of configural alteration was examined. Study 3 provides important information regarding the role of the FIE in the realm of face recognition research. Although many studies demonstrate that the FIE is mainly caused by the impairment of configural processing, Study 3 helps to clarify whether or not the emergence of the FIE is robust in any arbitrary configural alteration or is susceptible to the ratio of the configural alteration. The results of Study 3 provide enlightening information for future study, especially for those which apply only one ratio of the configural alteration throughout the whole research.

In the third section of this dissertation, the representation of face recognition is investigated from the perception of a single visual dimension, i.e. length perception in face images. In study 4, a novel illusion was demonstrated in face perception illustrating that length perception might be distorted in face perception. The effect of the illusion disappeared when the facial context was deleted. This novel illusion demonstrates that neighboring external contours lead to a distortion in length perception. In Study 4, three experiments (from Exp.7 to Exp.9) were constructed to explore the underlying mechanism of this novel illusion.

In the final section of this dissertation, a walking heuristic discovered in the Oerlikon campus of the University of Zurich (Switzerland) was investigated. It was found that many factors, such as familiarity, distance, time required, and priority might influence a human’s selection of routes when there are alternative options (Seneviratne & Morrall, 1985; for a review, see Golledge, 1999). Two heuristics has been discovered in route selection. Christenfeld (1995) demonstrated that people tend to avoid the middle routes and prefer the first (first priority) or the last (second priority) among multiple choices when required to select a route from A to B on a sheet. Bailenson, Shum, and Uttal (2000) also found that the initial straightness of the routes is critical for route selection. People rely on the ‘initial segment strategy’ during route selection. In Study 5, a novel heuristic of route selection is proposed and examined. An asymmetrical walking pattern was observed when students of the University of Zurich travelled across the road in the Oerlikon campus. As shown in Figure Ⅰ, students tend to walk to the zebra crossing to cross the road when moving from building A to building B (solid line). However, when they move from building B to building A (dotted line), they tend to cross the road directly rather than at the zebra crossing, although this path is more dangerous because of the heavy traffic. The asymmetry is different from the asymmetry observed in previous research. A new heuristic is proposed in Study 5 to explain the asymmetrical route selection.

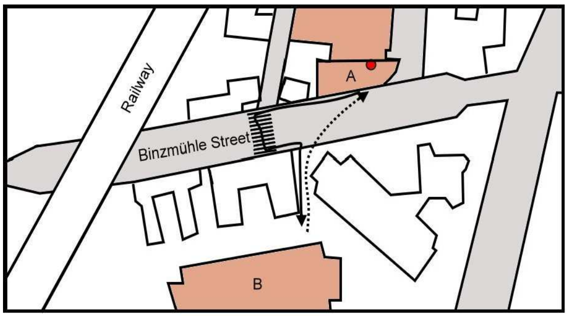

Figure Ⅰ. Illustration of the asymmetrical walking pattern in the Oerlikon campus of University of Zurich

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# 2 3D Mental Representations in Face Recognition Ⅰ: The Application of 3D Representations in Face Recognition

## 2.1 Abstract

Most current psychological theories of face recognition assume that faces are stored as multiple 2D views. This research aims to explore the application of 3D face representation by means of a new paradigm. Participants were required to match the frontal-view faces to their silhouettes. The formats of the face stimuli were modified in different experiments to make the 3D representation accessible (Experiment 1a- 2b) or inaccessible (Experiment 3a-b). Multiple 2D view-based algorithms are not applicable due to the singularity of the frontal-view faces. The results disclose the adaptability of 3D face representation. Asymmetrical race effects were found, revealing that European participants demonstrate the own-race advantage whereas Asian participants did not when the tasks demanded 3D face representation. These results may be due to the more protrusive and diagnostic 3D information in European faces.

## 2.2 Introduction

Face recognition plays an important role for social interaction. Despite all faces being composed of relatively few parts and sharing a unitary configuration, humans are able to distinguish exceedingly subtle differences between them. Although much research has been conducted in recent decades to investigate the underlying processes and representations of faces (for a recent review see Schwaninger, Wallraven, Cunningham, & Chiller-Glaus, 2006), it remains debatable whether 3D representations and viewpoint transformations exist in human face recognition.

According to object-centered theories (Marr & Nishihara, 1978; Biederman, 1987; Biederman, 2000), object recognition is based on structural descriptions which specify an object by its constituent parts, e.g. Geons and their spatial relations (Geon Structural Descriptions, GSD). Such descriptions are assumed to be object-centered, which provide the basis for view-invariant recognition. Biederman and Gerhardstein (1993) enhance the Recognition by Components (RBC) theory (Biederman, 1987) by specifying three prerequisites for viewpoint independent recognition. First, the objects must be decomposable into their parts. Second, the GSD for different objects must be distinctive. Third, the same GSD of a specific object must be recoverable from different viewpoints.

By contrast, view-based theories propose that objects are not stored as object-centered structural descriptions but as a collection of 2D views (Bülthoff & Edelman, 1992; Tarr & Pinker, 1989; Tarr & Bülthoff, 1995; Biederman & Kalocsai, 1997; Bülthoff, Edelman, & Tarr, 1995). Object recognition relies on matching a novel view of an object to the stored views by using different mechanisms, such as linear interpolation between views (Poggio & Edelman, 1990), multiple views plus transformations (Tarr & Pinker, 1989), or linear combination of views (Ullman & Basri, 1991).

Face recognition, however, has been suggested to implicate mechanisms that are different from those applying to object recognition. The distinct processes between object and face recognition are demonstrated from different research domains, such as behavioral studies (Yin, 1969), brain patients (Hecaen & Angelergues,1962; Yin, 1970; Ellis & Florence, 1990; Farah, 1991; Farah, Levinson, & Klein, 1995), and cognitive neuroscience studies (Desimone, 1991; Ojemann, Ojemann, & Lettich, 1992; Kanwisher, McDermott, & Chun, 1997; Kanwisher, Downing, Epstein, & Kourtzi, 2001). However, in contrast to the debate on 2D versus 3D representation in object recognition, it is generally assumed that faces are represented by a collection of 2D views (Biederman & Kalocsai, 1997; Bülthoff, Edelman, & Tarr, 1995).

Although Biederman and Kalocsai (1997) propose that object recognition is viewpoint-invariant, they further indicate that RBC applies only to basic level object recognition but not to face recognition. Due to the fact that all faces share the same basic components (eyes, nose, mouth, chin, etc.) in the same basic arrangement (the eyes are above the nose which is above the mouth), faces cannot be distinguished based on structural descriptions. Violation of the prerequisites of viewpoint invariant recognition makes it difficult for face recognition to have 3D representations. Instead, Biederman and Kalocsai (1997) argue that a holistic, view-dependent system such as the models proposed by Christoph von der Malsburg and his colleagues (Lades, et al., 1993; Wiskott, Fellous, Krüger, & von der Malsburg, 1997) are much more suitable to explain human face recognition. Moreover, several studies also suggest that face recognition is based on purely holistic and view-based processes using 2D representations rather than 3D representations (e.g., Tanaka & Farah, 1991, 1993; Lades, et al., 1993; Wiskott, et al., 1997). In a recent computational model, Wallraven, Schwaninger, and Bülthoff (2005) implement a view-based approach in which facial features and their spatial relations are stored in separate 2D views which are temporally associated. As shown in a set of different studies, this model could explain various aspects of human face recognition such as processing component and configural information (Schwaninger, Wallraven, & Bülthoff, 2004; Wallraven, et al., 2005) as well as specific effects of viewpoint (Wallraven, Schwaninger, Schuhmacher, & Bülthoff, 2002; Schwaninger, Schumacher, Wallraven, & Bülthoff, 2007).

Accordingly, the 3D face representations which require the processes of utilizing the shading and shadow information to reconstruct the three-dimensional shape of the faces may be absent for humans in many face recognition models (Bruce, 1988; Johnson, Hill, & Carman, 1992; Bruce & Langton, 1994; Vetter, 1998). It is only in the domain of computer vision that 3D models and processes of faces have been implemented (Vetter, 1998; Blanz & Vetter, 1999; for a recent review of cognitive and computational models of face recognition see Schwaninger, et al, 2006).

However, at least three different research lines provide converging results suggesting that human face recognition may involve 3D representation mechanisms more than mere match of multiple 2D face views. The first line of evidence comes from research regarding the recognition of one's own profile. Troje and Kersten (1999) find that humans can recognize profile views of their own faces, even though such views are usually not encountered and thus are hardly available in visual memory. Tong and Nakayama (1999) report further interesting research. In a visual search task, their participants demonstrated an equivalent own-face advantage across frontal, three-quarter, and profile views. Their results are surprising when taking into account that the observers had equal amounts of visual experience of the stranger's frontal and profile view, but far greater experience of their own frontal face view than their profiles. They argue that people can develop robust representations for highly over-learned faces, such as the face of one's own. This representation might involve viewpoint-invariant 3D representation. However, participants in Tong and Nakayama's study might have relied on facial texture information to recognize the depth-rotated profiles of their own faces, because it has been found that information such as skin color, pigment, or texture features provide important information to reduce viewpoint dependence in face recognition

(Hill, Schyns, & Akamatsu, 1997). Moreover, face features such as skin texture, blemishes, and dimples may be visible from largely different viewpoints (O'Toole, Bülthoff, Troje, & Vetter, 1995).

The second line of evidence suggesting the application of 3D face representation in humans comes from haptic face recognition research. Kilgour and Lederman (2002) found that participants' performance (67.8%) was higher than chance (33.3%) when they were shown the motionless life faces, and were required to subsequently recognize them by touching (haptic recognition). Their results imply that participants can construct a multimodal 3D representation of faces based on mere visual exposure. Casey and Newell's (2003) research regarding haptic own-face recognition also supports this assumption. They found that a greater amount of target faces were correctly identified when own-face masks were oriented towards participants, contrary to the orientation in which a haptic representation of one's own face is naturally generated. These findings suggest that human might be able to construct a 3D representation of their own face via the large amount of visual experience. Viewers might then engage this 3D representation in own-face haptic recognition where geometric properties are the only cues for correct identification. Although far from the same domain, Casey and Newell's results surprisingly correspond to the notion of Tong and Nakayama (1999) that a robust viewpoint-invariant representation is formed for highly over-learned faces.

The third line of evidence comes from the studies associated with brain neuron activation. Grill-Spector et al (1999) found that both caudal-dorsal (LO) and posterior fusiform (PF-LOa) in lateral occipital complex (LOC) are maximally activated by images of different individuals' faces. However, the activation is adapted by repeated presentation of identical individual faces, either in original viewing condition or depth rotation condition. The adaptations for original viewing condition and depth rotation condition are equivalent in PF-LOa region. They argue that PF-Loa is more invariant to changes in the object's position in the visual field compared to LO. Similarly, Chen, Kao, and Tyler (2006) also observed that brain activation is significantly different between frontal-view and inverted faces, but not between frontal-view and 3/4-view faces. These results suggest that there may be neural circuits responsible for the viewpoint invariance of face representation. In fact, a small portion of cells in the macaque superior temporal sulcus (STS) has been identified to response equally to multiple views of a face (Perrett, et al, 1991).

Despite that the results from the three lines of research imply the application of 3D face representations in humans, these studies eventually did not directly examine the mechanisms of 3D face representations. In this research, I adopt the 'face silhouette vs. frontal-view faces matching' paradigm which is to match a one-tone black silhouette to their frontal-view faces (Davidenko, 2007). This task can be solved by extracting 3D information, such as shading and shadow information contained in the face photographs (Bruce & Langton, 1994), reconstructing the 3D structure of faces (Bruce et al ,1991; Vetter, 1998), mentally rotating this 3D face model ( Vetter, 1998; Blanz & Vetter, 1999), and matching it to the one-tone black silhouette. This task cannot be solved by matching 2D information contained in the faces, such as face configuration, texture, color, blemishes, dimples, etc. Moreover, it cannot be solved by linear combination theories because a small set of 2D views are necessary for constructing 3D models by linear combination (Ullman & Basri, 1991; Poggio, 1990). Although Poggio and his colleagues propose that for bilaterally symmetrical objects such as faces, only one non-accidental 2D view is sufficient for recognition (Poggio, 1991; Poggio & Vetter, 1992; Beymer & Poggio, 1995). They constrain their conclusion by specifying: "*one should avoid to use in* *the data base a model view which is a fixed point of the symmetry transformations (since the transformation of it generates an identical new view). In the case of faces, this implies that the model view in the data base should not be an exactly front-view*" (Poggio & Vetter, 1992, *p*. 15). Basically, the frontal-view face is singular and a second view cannot be computed from it (Schyns & Bülthoff, 1993). As a result, a silhouette cannot be generated from just one frontal-view face image by algorithms of different 2D view-based models. For the view-based approach of face recognition theories, matching a frontal-view face to its one-tone black silhouette would be improbable because both surface information and multiple views integration are not applicable. Moreover, the shape information in the silhouettes is not directly observable in their frontal-view counterparts (Davidenko, 2007). Consequently, a frontal-view face image and its corresponding one-tone black silhouette serve as an optimal pair to examine the application of 3D face representations.

This research aims to adopt this new paradigm to examine whether 3D face representation mechanisms exist and whether they demonstrate typical characteristics found for face recognition such as inversion effect (Yin, 1969, for a review see Valentine, 1988) and own race advantage (for a review see Meissner & Brigham, 2001). Three experiments consisted of six sub-experiments were conducted to address this issue. Throughout the research, both Asian and European participants were recruited to compare the potential race effect in face recognition (Goldstein & Chance, 1979; Hayward, Rhodes, & Schwaninger, 2008).

## 2.3 Experiment 1a & 1b

In Experiment 1, I examine whether participants can match frontal-view faces to their corresponding profiles. This experiment aims to explore how well human can perform the viewpoint-transformation task under the condition that the face images are different while the texture and pictorial information are reserved. The intermediate views between the frontal-view and the profile view were not available. Although the direct pictorial matching of faces is prevented, participants can still rely on other image-based information, e.g. the facial texture, the size and shape of the features, to accomplish the task. The grayscale profiles of the frontal-view faces were adopted based on the findings that facial color or reflectance cues play an important role in face recognition (Alley & Schultheis, 2001; Yip & Sinha, 2002; Russell, Biederman, Nederhouser, & Sinha, 2007). Moreover, Hill, Schyns, and Akamatsu (1997) also find that facial information, such as skin color, pigmented, or textured features provide important information to reduce viewpoint dependence in face recognition. Accordingly, adopting full color images for both frontal-view and profile face images might encourage participants to merely rely on the skin tone to match the faces, particularly when faces are presented simultaneously. By contrast, Russell et al (2007) reported that it is more difficult to extract reflectance information for face recognition in grayscale face images. Consequently, I adopted the recognition between full color frontal-view face and grayscale profiles to reduce participants from relying only on the reflectance (color) cues during the matching task. Experiment 1 is divided into two sub-experiments 1a and 1b according to the procedure adopted. Experiment 1a presented the target face and the testing faces simultaneously. Experiment 1b, however, presented the target face and the testing faces sequentially to avoid the concurrent pictorial, picture-based recognition.

2.3.1 Method

2.3.1.1 Participants

Throughout the whole research (Exp 1a to Exp 3b), the data were collected in Switzerland and Taiwan separately. All the participants in Switzerland were Europeans and were recruited from University of Zurich; all the participants in Taiwan were Asians and were recruited from National Chung-Cheng University. All of them participated in only one of the six different experiments.

2.3.1.1.1 Experiment 1a

Eighteen European students (6 male, mean ages 22.96) from Switzerland and seventeen students (11 male mean ages 21.49) from Taiwan participated in Experiment 1a.

2.3.1.1.2 Experiment 1b

Eighteen European students (5 male, mean age = 23 years) from Switzerland and twenty students (11 male, mean age = 24.8 years) from Taiwan participated in Experiment 1b.

2.3.1.2 Materials

Full-color frontal and profile view photographs of 16 Europeans and 16 Asians were taken. Half of these faces were male for each race. The profile images were converted to grayscale images by PhotoImpact 10. To avoid participants from matching the faces by hair-styles and forehead fringe across different faces, the distances between the lowest hair cue in the forehead and the concave of the nose of all the faces were measured. The minimum distance among the faces in the same set was taken as the standard length for all the faces in the same set (same face race and gender). The faces in the same set were trimmed to the same extent based on the standard length. In addition, the hair cue that remained visible after the primary trim was further cropped. The middle images in Figure 1a, and 1b display examples of the grayscale profile.

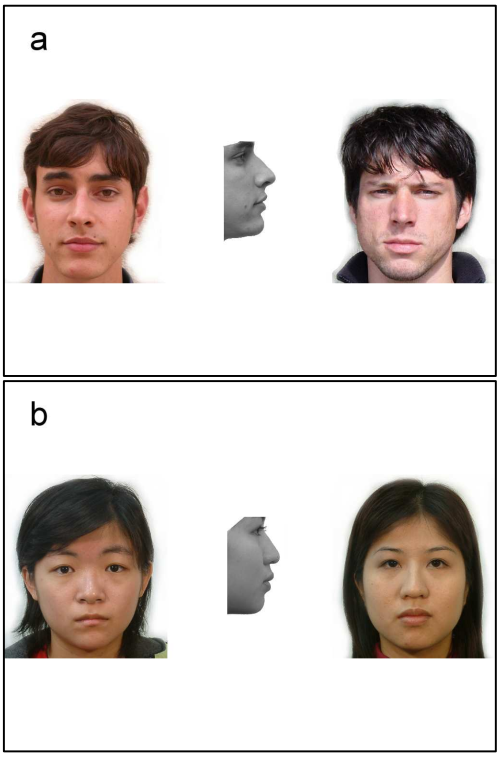

Figure 1. Illustration of experimental stimulus and trials in Experiment 1a.

2.3.1.3 Procedure

Experiment 1a and 1b were both three-factor mixed design with face race and orientation as within-participant factors, and participant group (European vs. Asian) as between-participant factor. All possible combination pairs between the eight exemplars faces in the same set were included which rendered 28 pairs for each face set. Among the 28 pairs for each set, the same frontal-view faces were balanced to show up in the left side or right side of the profile. In addition, the direction (towards right or left) of the profiles and the position of the correct target faces (towards right or left) were also balanced. In half of the trials, the profile faced towards the right and in the other half towards the left. Among the trials of the profiles facing towards the left, half of the correct target frontal-view faces were arranged on the left side (congruous direction) and half on the right sides (incongruous direction). The manipulation was applied also for the trials of the profiles facing towards the right. The 224 trials, 4 face sets × 28 combinations × 2 orientations (upright and inverted), were randomly presented in formal experiment.

#### 2.3.1.3.1 Experiment 1a

For each trial, a grayscale profile was positioned in the middle of the screen and two full color frontal-view faces flanked on either side of the profile. The two frontal-view faces and the grayscale profile were not positioned on the same horizontal line so as to reduce direct comparison of the inter-distance between face features. Figure 1a and 1b illustrate examples of the trials for one European male face and one Asian female face. The lines in Figure 1 denote the border of the 17" CRT monitor. The flank two frontal-view faces were consistently presented upright whereas the middle grayscale profile could be presented upright or inverted. Participants were instructed to match the grayscale profile to either the right or the left frontal-view faces and then press the corresponding key. The experiment is self-paced without constraint on the presentation time. Participant's heads were not fixed and the viewing distance was about 50 cm. Participants were provided with eight practice trials balanced in face race, face direction, orientation, and face gender before the formal experiment. The face images that appeared in the practice trials were not shown again in the formal trials.

#### 2.3.1.3.2 Experiment 1b

The design and arrangement of the trials were identical to Experiment 1a except for that the target frontal view face and the testing profile faces were presented sequentially. In each trial, a frontal-view face was presented on the screen for 3000 ms, which is followed by a blank (black) mask for 500 ms. Two grayscale profiles, one in the left and one in the right, succeeded the mask image. Participants were instructed to judge which of the two profiles was the transformation of the preceding frontal-view face. The frontal-view face was consistently presented upright whereas the grayscale profiles could be presented upright or inverted.

### 2.3.2 Results

#### 2.3.2.1 Accuracy

Throughout the whole research, the data of accuracy were subjected to a repeated measures analysis of variance (ANOVA) with face race and orientation as within-participant factors, and participant group (European vs. Asian) as between-participant factor.

##### 2.3.2.1.1 *Experiment 1a*.

Figure 2 displays means and standard errors of percent correct responses (accuracy) in Experiment 1a.

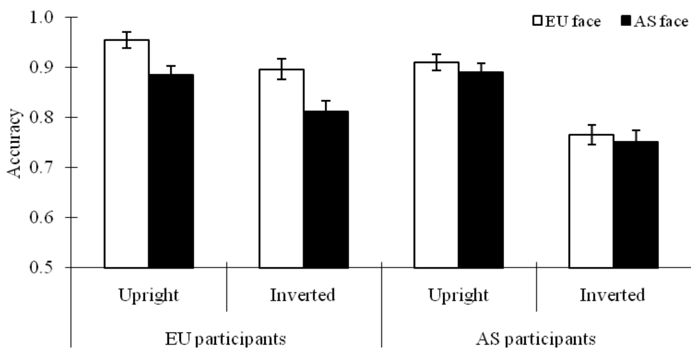

Figure 2. Means and standard errors of accuracy in different conditions of Experiment 1a.

The repeated measures ANOVA revealed main effects of face race, $F(1,33) = 28.38$, $MSE = .08$, $p < .001$; orientation, $F(1, 33) = 115.96$, $MSE = .38$, $p < .001$; and participant group, $F(1, 33) = 7.77$, $MSE = .12$, $p < .009$. Performances were better in the recognition of European faces and upright faces. Moreover, the performance of European participants was better than that of Asian participants. The ANOVA also revealed significant interaction between face race and participant group, $F(1, 33) = 11.81$, $MSE = .03$, $p < .001$, and between orientation and participant group, $F(1, 33) = 14.9$, $MSE = .05$, $p < .001$. Simple main effect analysis for interaction between face race and participant group revealed that European participants performed better in the recognition of European faces (M = .93) than Asian faces (M = .85), $F(1, 17) = 32.53$, $MSE = .11$, $p$

< .001; but Asian participants performed comparably in the recognition of the two different ethnic faces (European face, M = .84; Asian face, M = .82), $p$ > .15. Simple main effect analysis for interaction between orientation and participant group revealed that European and Asian participants were equivalent in the recognition of upright faces, $p$ > .27; whereas European participants prevailed over Asian participants in the recognition of inverted faces, $F$(1, 33) = 6.87, $MSE$ = .02, $p$ < .013. No other main effects or interactions were significant.

2.3.2.1.2 <u>Experiment 1b</u>.

Despite that the overall performance declines when a sequential presentation paradigm was adopted (Exp 1a, M= .86; Exp 1b, M=.81), Experiment1b revealed similar pattern as obtained in Experiment 1a. Figure 3 displays means and standard errors of accuracy in Experiment 1b.

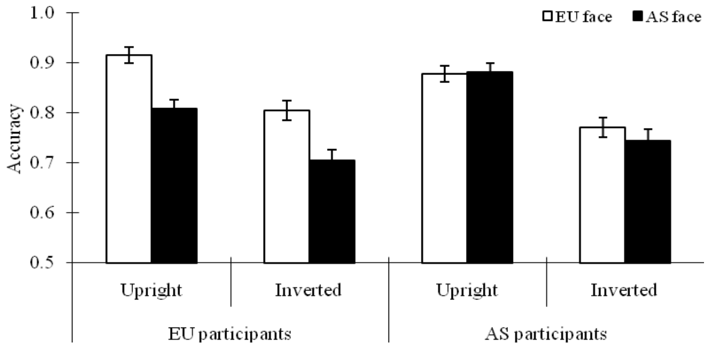

Figure 3. Means and standard errors of accuracy in different conditions of Experiment 1b.

The repeated measures ANOVA revealed main effects of face race, $F$(1,36) = 30.99, $MSE$ = .13, $p$ < .001 and orientation, $F$(1,36) = 122.92, $MSE$ = .50, $p$ < .001 . The ANOVA also revealed significant interaction between face race and participant group, $F$(1, 36) = 19.38, $MSE$ = .08, $p$ < .001. Simple main effect analysis for the interaction between face race and participant group revealed that European participants performed better in the recognition of European faces (M = .86) than matching Asian faces (M = .76), $F$(1, 17) = 45.79, $MSE$ = .19, $p$ < .001; but Asian participants performed equally well in the recognition of the two different ethnic faces (European face, M = .83; Asian face, M = .81), $F$ < 1.

2.3.2.2 Chance level t-tests

Throughout the whole research, two tailed T-tests were conducted separately for the eight different conditions to test whether or not the performances were higher than chance level (0.5).

2.3.2.2.1 Experiment1a

The performances in all the eight conditions were significantly higher than chance level (*p*s < .001).

2.3.2.2.2 Experiment1b

The performances in all the eight conditions were significantly higher than chance level (*p*s < .001).

2.3.3 Discussion

The results in both experiments show that participants can readily match the grayscale profiles to their corresponding frontal-view faces. Although the texture information would be helpful during the task, it would not be the only information that participants relied on to accomplish the task. The matching process may also involve in 3D representations of faces based on the following inferences. If participants relied merely on the texture information to match the faces, the inversion effect and the asymmetrical race effect should not be demonstrated. After all, both upright and inverted conditions provide equivalent texture information, and participants from both ethnic groups were provided with the same amount of texture information. The inversion effect and the asymmetrical race effect could possibly be arisen from the incomparable 3D face representations between different orientations and between participants from different ethnic groups.

Intriguingly, Experiment 1a and 1b both demonstrated asymmetrical race effect for participants from different ethnic groups. European participants performed better in European faces than Asian faces, whereas Asian participants performed comparably between European and Asian faces. The asymmetric race effect was in accordance with previous research as European participants often reveal race effect, whereas Asian or Africa American participants don’t (Tanaka, Kiefer, & Bukach, 2004; Barden, Maddux, Petty, & Brewer, 2004).

## 2.4 Experiment 2a & 2b

In Experiment 2, the grayscale profiles were replaced by one-tone black silhouettes. As discussed earlier, the one-tone black silhouette can further prevent participants from relying on any pictorial cue that is available in profile. This task would demand participants to extract the 3D information from the facial front-view, form a 3D face representation, mentally rotate it, and then match it to the silhouette. The results can provide a direct and critical examination regarding whether or not humans have 3D representations in face processing. Similar to Experiment 1, Experiment 2 is also divided to two sub-experiments. The target and testing faces were presented simultaneously in Experiment 2a and sequentially in Experiment 2b.

### 2.4.1 Method

#### 2.4.1.1 Participants

##### 2.4.1.1.1 Experiment 2a

Eighteen European students (2 male, mean ages 24.5) from Switzerland and sixteen students (9 male, mean ages 20.85) from Taiwan participated in Experiment 2a.

2.4.1.1.2 Experiment 2b

Eighteen European students (1 male, mean age = 24.61 years) from Switzerland and sixteen students (5 male, mean age = 21.52 years) from Taiwan participated in Experiment 2b.

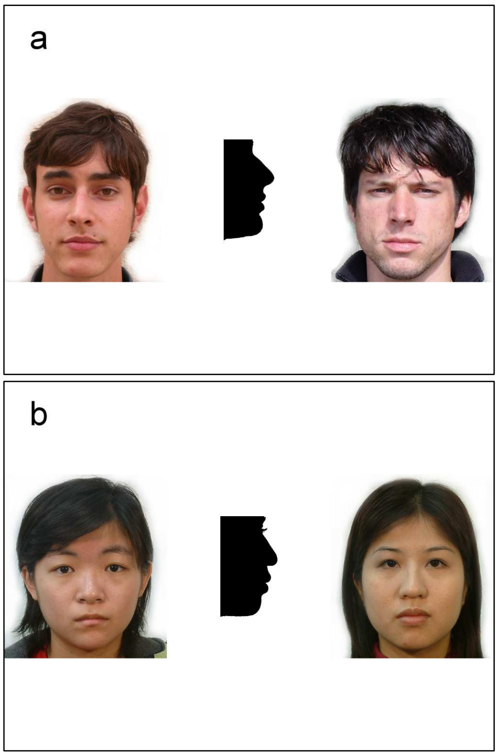

Figure 4. Illustration of experimental stimulus and trials in Experiment 2a.

2.4.1.2 Materials

The face stimuli were identical to those used in Experiment 2 but the gray-scale profiles were transferred to one-tone black silhouettes by PhotoImpact 10. Figure 4a, and 4b display examples of the corresponding images in Figure 1.

2.4.1.3 Procedure

The design and arrangement of the trials were identical to those in Experiment 1. Similar to Experiment 1, Experiment 2 is also divided into two sub-experiments 2a and 2b with different procedures. The target and testing faces were presented simultaneously in Experiment 2a, but they were presented sequentially in Experiment 2b.

### 2.4.2 Results

#### 2.4.2.1 Accuracy

##### 2.4.2.1.1 Experiment 2a

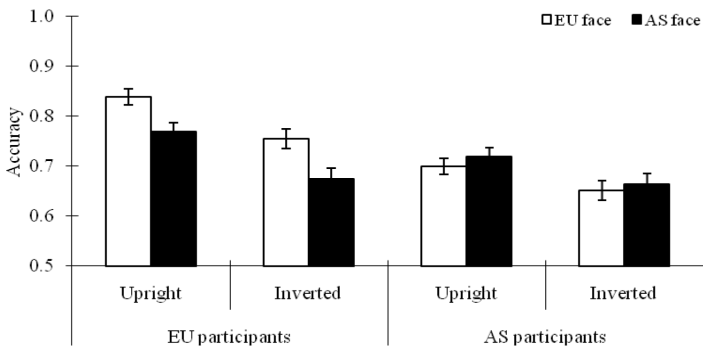

Figure 5. Means and standard errors of accuracy in different conditions of Experiment 2a.

Figure 5 displays means and standard errors of accuracy in Experiment 2a. The repeated measures ANOVA revealed main effects of face race, $F(1,32) = 5.73$, $MSE = .03$, $p < .023$; orientation, $F(1, 32) = 50.07$, $MSE = .17$, $p < .001$; and participant group, $F(1,32) = 6.78$, $MSE = .20$, $p < .014$. The results were identical to that in Experiment 1a, revealing that performances were better in the recognition of European faces and upright faces. Moreover, the performance of European participants was better than that of Asian participants. The ANOVA also revealed significant interactions between face race and participant group, $F(1, 32) = 13.29$, $MSE = .07$, $p < .001$. Simple main effect analysis of the interaction between face race and participant group revealed that European participants performed better in matching European faces (M = .80) than matching Asian faces (M= .72), $F(1, 17) = 24.45$, $MSE = .10$, $p < .001$, whereas Asian participants performed comparably in matching faces of both races (European face, M = .68; Asian face, M = .69), $F<1$. No other main effects or interactions were significant.

##### 2.4.2.1.2 Experiment 2b.

Figure 6 displays means and standard errors of accuracy. The repeated measures ANOVA revealed main effects of face race, $F(1,32) = 25.76$, $MSE = .08$, $p < .001$, and orientation, $F(1, 32) = 57.50$, $MSE = .20$, $p < .001$. The interaction between face race and participant group was also significant, $F(1, 32) = 5.19$, $MSE = .02$, $p < .03$. The three-way interaction between face race, orientation, and participant group was also significant, $F(1, 32) = 4.23$, $MSE = .13$, $p < .048$. To clarify the source of the interaction, separate ANOVAs were conducted for European and Asian participants.

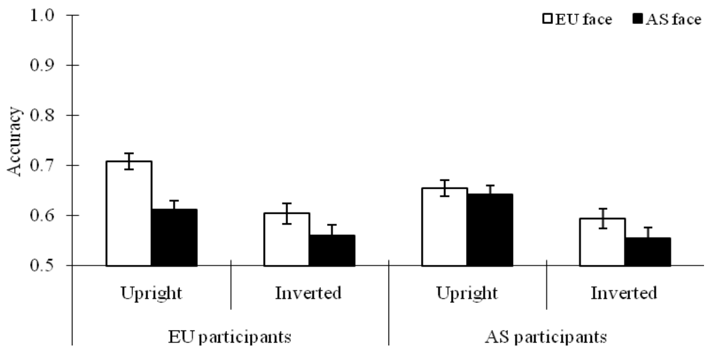

Figure 6. Means and standard errors of accuracy in different conditions of Experiment 2b.

2.4.2.1.2.1 European participants. The ANOVA revealed significant main effects of face race, $F(1,17) = 29.04$, $MSE = .09$, $p < .001$, and orientation, $F(1, 17) = 27.90$, $MSE = .111$, $p < .001$. Both the inversion effect and own-race advantage were demonstrated.

2.4.2.1.2.2 Asian participants. Only the main effect of orientation was significant, $F(1,15) = 31.073$, $MSE = .09$, $p < .001$.

2.4.2.2 Chance level t-tests

2.4.2.2.1 Experiment2a

The performances in all the eight conditions were significantly higher than chance level ($p$s < .001).

2.4.2.2.2 Experiment2b

The performances in all the eight conditions were significantly higher than chance level ($p$s < .012).

### 2.4.3 Discussion

The results show that participants were able to match a frontal-view image to its corresponding one-tone silhouette image even though all the view-based information, such as the facial texture, pictorial matching etc., were not available. The results of Experiment 2 provide essential support for the application of 3D representation in face processing. Participants did not have a depth-rotated representation of the frontal-view face in their memory because the faces were unfamiliar to them. Moreover, as described in the introduction section, multiple 2D view-based algorithms are not applicable under this condition (Poggio & Edelman, 1990; Tarr & Pinker, 1989; Ullman & Basri, 1991). Various 2D view-based theories of face recognition seem insufficient to explain the results that participants can readily match the one-tone black silhouettes to the corresponding frontal-view faces.

The principal patterns of Experiment 1 remain unchanged in Experiment 2. The face inversion effect and the asymmetric race effect obtained in Experiment 1 were again replicated in Experiment 2. These results suggest that the 3D face representations and the underlying processes might be constrained to some specific face expertise e.g. humans are only experts in recognizing upright faces and own race faces. The asymmetrical race effect reveals that European participants still performed better in the recognition of European faces than Asian faces, while Asian participants performed equally well between the two different ethnic faces.

## 2.5 Experiment 3a & 3b

In the previous four sub-experiments, the 3D information in the faces is essential during the tasks. Experiment 3 serves as a control experiment to examine how participants perform when the 3D information is hardly retrievable in faces. The frontal-view faces were replaced by line drawing faces. The line drawing face images which are free from any shadow and shading information contain hardly any cues for 3D representation (Bruce, & Langton, 1994; Kemp, Pike, White, & Musselman, 1996; Liu, Collin, Burton, & Chaudhuri, 1999) and are more difficult to be recognized than normal faces (Davies, Ellis, & Shepherd, 1978; Rhodes, Brennan, & Carey, 1987; Leder, 1996). The lack of sufficient 3D information cues in line drawing faces might force participants to rely only on other information to recognize the silhouettes, e.g., the estimation of the size of the facial feature (nose, mouth, chin, etc.) or the distance between facial features. This experiment can further examine the contribution of these strategies.

### 2.5.1 Method

#### 2.5.1.1 Participants

##### 2.5.1.1.1 Experiment 3a

Eighteen European students (2 male, mean age = 23 years) from Switzerland and twenty students (4 male, mean age = 21.99 years) from Taiwan participated in Experiment 3a.

2.5.1.1.2 Experiment 3b

Eighteen European students (3 male, mean age = 25.52 years) from Switzerland and eighteen students (8 male, mean age = 20.81 years) from Taiwan participated in Experiment 3b.

2.5.1.2 Materials

The face images were identical to Experiment 1 and 2. However, the targeting frontal-view faces were converted to line drawing faces. The line drawings of the faces were manually depicted from the original faces by Photoimpact 10. All the line drawing faces were created in the same manner and by the same experimenter. Figure 7a and 7b display examples of the corresponding images in Figure 4.

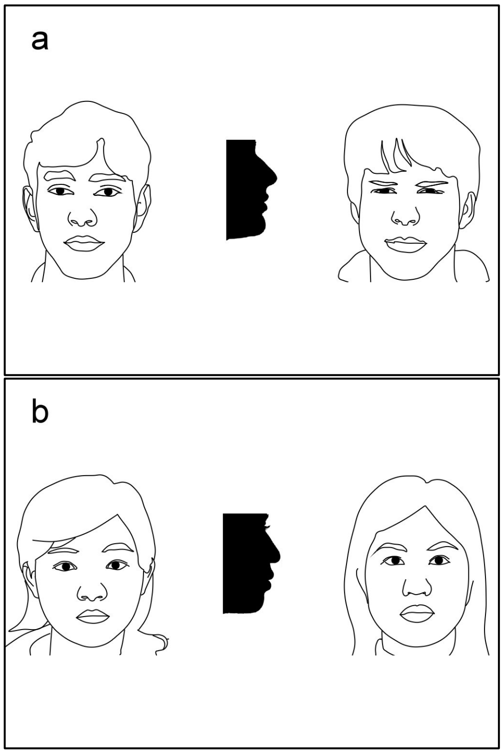

Figure 7. Illustration of experimental stimulus and trials in Experiment 3a.

2.5.1.3 Procedure

The design and procedure were identical to that in Experiment 1 and 2. Similar to previous experiments, Experiment 3 is also divided to two sub-experiments with different presentation paradigms. The target and testing faces were presented simultaneously in Experiment 3a, but they were presented sequentially in Experiment 3b.

2.5.2 Results

#### 2.5.2.1 Accuracy

##### 2.5.2.1.1 Experiment 3a

Figure 8 displays means and standard errors of the accuracy in Experiment 3a.

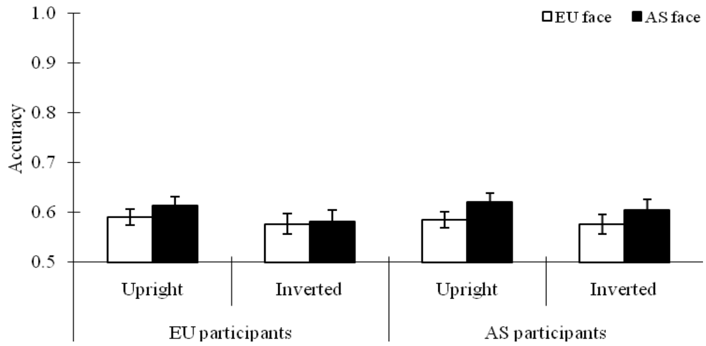

Figure 8. Means and standard errors of accuracy in different conditions of Experiment 3a.

The repeated measures ANOVA revealed only main effect of face race, $F(1,38) = 4.96$, $MSE = .02$, $p < .032$. However, different from previous experiments, participants were better in the recognition of Asian faces (M= .61) than European faces (M= .58). No other main effects or interaction effects were significant.

##### 2.5.2.1.2 Experiment 3*b*

Figure 9 displays means and standard errors of the accuracy in Experiment 3b.

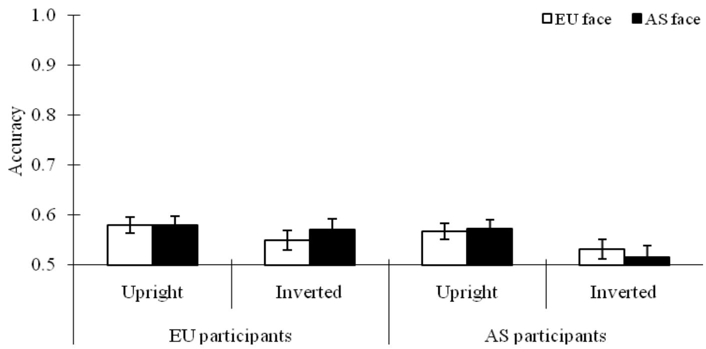

Figure 9. Means and standard errors of accuracy in different conditions of Experiment 3b.

The repeated measures ANOVA revealed only main effect of orientation, $F(1,34) = 12.70$, $MSE = .04$, $p < .001$.

#### 2.5.2.2 Chance level t-tests

#### 2.5.2.2.1 Experiment 3a

The performances in all the eight conditions were significantly higher than chance level (*p*s < .002).

#### 2.5.2.2.2 Experiment 3b

The performance was equal to chance level in the recognition of inverted Asian faces for Asian participant (*p* > .396). Performances in all the other conditions were significantly higher than chance level (*ps* < > .034) despite the accuracy is very low.

### 2.5.3 Discussion

The results of Experiment 3 show that the performances were still higher than chance level in most of the conditions. It suggests that participants might still rely on some information contained in the line drawings to accomplish the task. For example, estimation of the sizes or shape of the mouth, nose, or chin, especially when the differences of the size are large between the two testing faces as shown from Figure 10a to 10c. In these examples, the sizes of the mouths between the two ing faces have substantial difference which can easily be observed. These matching strategies might explain why the accuracy remains higher than chance level in most of the conditions when the 3D information in faces is eliminated. Nevertheless the contribution from these matching strategies is relatively low as the performance significantly declined in line drawing faces of which the essential 3D information is substantially reduced. (Davies, Ellis, & Shepherd, 1978; Rhodes, Brennan, & Carey, 1987). The lack of 3D information in faces might be a critical factor to explain the low performance as it has been found that the addition of the shading information can significantly prove the recognition of cartoon (line ings) faces (Bruce, Hanna, Dench, Healey, & Burton, 1992). The influence of the insufficient 3D information might cause even severer impact on the performance when the task demands sufficient 3D representations as in current experiments.

Experiment 3 also reveals important insight regarding the essence of face representation in different face formats. It shows that the inversion effect and asymmetrical race effect both vanish when participants can only recognize the faces by the estimation of the sizes or shape of the facial features, the relative distances between facial features, or other possible strategies. Though the inversion effect restored in Exp 3b, it might mainly arise from the chance level in the recognition of inverted faces. The results of Experiment 3 imply that the emergence of inversion effect and the asymmetrical race effect are mainly arisen from the application of 3D face representation. In Experiment 3a, the results show that participants are better in the recognition of Asian faces then European faces. This finding reveals a contrary pattern to that found in Experiment 1 and 2 in which European face were consistently better recognized. These results further rule out the assumption that the results in

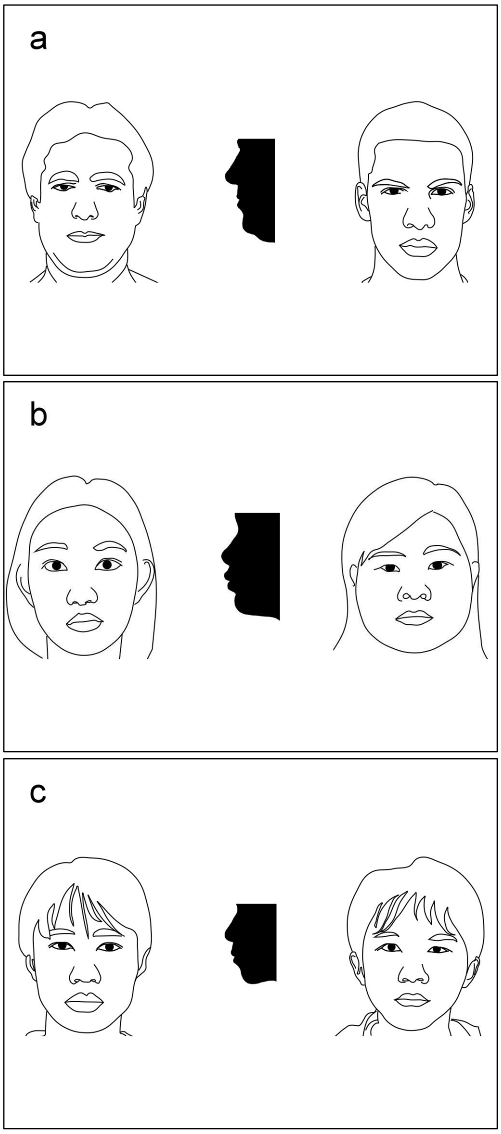


Figure 10. Illustrations of the substantial size difference of the mouths for the two testing faces.

Experiment 1 and 2 might be due to the different extent of discriminability between European faces and Asian faces. It suggests that the facial variability, at least in the planar level, might even be higher in Asian faces than in European faces.

### 2.6 Comparisons between Experiments 1-3

From Experiment 1 to 3, only the formats of face stimuli were altered. In Experiment 1, the profile faces enable participants to match the faces not only by the 3D representations but also by various pictorial information, i.e. the texture information, the size of features, the distances between features, etc. In Experiment 2 with silhouette images, 3D representations of the faces were essential information for the accomplishment of the task. The 2D view-based representation was apparently not applicable. In experiment 3 with line drawing images, the 3D representations of faces are hardly retractable and participants might rely on different strategies to complete the task e.g. estimation of the size or shape of the facial features, or the relative distances between the face features. The comparisons between different experiments might provide important information regarding the characteristics of face representation in face images with different formats. To compare the performance in different experiments, all the data were pooled together with two new factors, i.e. Experiment (3 levels: Exp1, Exp 2, and Exp3) and Paradigm (2 levels: Simultaneous and sequential presentation). A repeated measures analysis of variance (ANOVA) was conducted with face race and orientation as within-participant factors, and participants group, experiment, and paradigm as between-participant factors. Only the effects concerning the new factor (Experiment & Paradigm) were reported. The main effect of Experiment was significant, $F(2,205)$ =

322.96, *MSE* = 5.15, *p* < .001. The post hoc pair-wise comparisons with Bonferroni adjustment revealed that all the pair-wise comparisons were significant. Performance in Exp 1 (M = .84) was significantly better than that in Exp 2 (M=.67) and both of them were significantly better than that in Exp 3 (M=.58). The main effect of Paradigm was also significant, $F(1,205) = 51.81$, $MSE = .83$, $p < .001$. Performance was better when the faces were presented simultaneously (M=.73) than when the faces were presented sequentially (=.66). The interaction between Experiment and Paradigm was also significant, $F(2,205) = 6.29$, $MSE = .10$, $p < .003$, indicating that the paradigm alteration seems to have a stronger impact on silhouette images (M=.72 vs. M=.62) than on profile images (M=.86 vs. M=.81) and line drawing images (M=.59 vs. M=.56) despite the paradigm causes significant effect on all the three experiments.

## 2.7 General Discussion

In this paper, I adopted a new paradigm to investigate the application and characteristics of 3D face representation. Participants were required to match the frontal-view faces to their profiles (Experiment 1) or silhouettes (Experiment 2), or to match the line drawing faces to their silhouettes (Experiment 3) in either simultaneous or sequential presentation paradigm. The results reveal that participants can readily solve the tasks when the face images retain essential information necessary for the formation of 3D face representation. The performance substantially declined when the 3D information in face are eliminated.

The results not only provide converging evidence to support the existence of 3D face representation, but also reveal important characteristics regarding the 3D face representation in different Ethnic groups and in different formats of face images. In Experiment 1 and 2, only the frontal-view face was presented. Accordingly, various view-based transformation algorithms are not applicable to generate the profile (or silhouette) view from the frontal-view face due to the singularity of the frontal-view face (Schyns & Bülthoff, 1993). The results of Experiment 2 provide critical evidence regarding the existence of 3D face representation. The possibility that participants might base their judgment on the size or shape of face features, or inter-distance between features further was further examined from the results of Experiment 3. In addition, different behavioral patterns were demonstrated when participants were required to recognized faces in different formats. In Experiment 1 and 2, participants' performances were higher than chance level in all different conditions when plentiful 3D information is accessible. However, the performances severely decline in Experiment 3 of which 3D information is substantially reduced.

A striking finding in this research is the asymmetrical race effect obtained in Experiments 1 and 2. The 3D face representation seems to be more robust in Europeans participants than Asian participants, and in Europeans faces than in Asian faces. It shows that European participants demonstrated an own-race advantage while Asian participants did not. European participants performed better in the recognition of European faces than Asian faces, whereas Asian participants performed comparably between the recognition of European faces and Asian faces. In addition, European participants prevailed over Asian participants when the task required explicit 3D face representation despite the precedence is restricted to the recognition of European faces. However, the asymmetrical race effect vanishes when the 3D face representation is not applicable as in line drawing face images. These characteristics might be arisen from the different facial characteristic between faces of the two different ethnic groups. Apparently, the European faces have more protrusive and diagnostic 3D information than Asian faces. Enlow (1982) has described two extreme forms of faces referred to as 'leptoprosopic' and 'euryprosopic' faces. The leptoprosopic face is narrower, more convex, and with more protrusive features as generally witnessed in European faces, whereas the euryprosopic face is rounder, more planar, and with flatter features as generally witnessed in Asian faces. Clearly, Europeans frequently encounter European faces with more salient 3D information embedded. With the large amount of face recognition experience in lives, Europeans might become more sensitive to the salient 3D information in European faces and develop more robust 3D representation for European faces. In other words, this advantage might be a consequence of learning effect from residential environment. However, the seemingly more robust 3D face representation for Europeans is restricted to the European faces because Asian faces are comparatively less eminent in their facial 3D information. The less diagnostic 3D information in Asian faces may also become an critical factor that renders Asians less sensitive to the 3D information in both Asian and European faces. After all, explicit 3D face representation is not enhanced in the Asian's living environment. Eventually, Asians become less sensitive to the 3D information in Asian faces as well in European faces. The less distinguishable 3D facial characteristic in Asian faces might also lead Europeans become less efficient in extracting the 3D information in Asian faces. As a result, Europeans reveal own race advantage whereas Asians do not when the tasks involve 3D face representation. However, Asians can still process the 3D information within faces and form 3D face representations because their performance is still substantially higher than chance level in Experiments 1 and 2.

Another interesting finding in the research is the fluctuation of the inversion effects in different experiments. The inversion effect was demonstrated when the tasks demanded explicit application of 3D face representation, whereas it is substantially weakened when the 3D information in faces was eliminated (Experiment 3). The emergence of an inversion effect in Experiment 2 provides especially important evidence to contradict the assumption that participants in the experiment merely rely on the distances between features to match the faces. Schwaninger, Ryf, and Hofer (2003) find that the inversion effect disappears when participants were required to compare the distances between face features during face recognition task. Merely comparing the distances between face features is a relatively lower level processing which would not lead to the emergence of an inversion effect. Results of Experiment 3 correspond to this notion.

Despite that the existence of the 3D face representation is supported in the current research, the mechanism of 3D face representation seems different from the representation defined by any current 3D representation models, such as the object-centre models (Marr, 1982; Biederman, 1987) or the 3D computational approach of face recognition model (Blanz &Vetter, 1999). For example, from the perspective of RBC theory, the geons and the GSD are expected to be clearly represented for further recognition. However, those were not the case in one-tone black silhouettes. The 3D representations of faces are obviously not limited to the representation of geons and their structural description, because all the faces are identical in their structural description. Hence, the 3D representation of faces may not be a purely viewpoint invariant 3D face representation, but a representation based on expertise that favors the transformation in an upright orientation and in an own race face, especially for Europeans.

In sum, this research brings to attention the lack of concern regarding the application of 3D representations in face recognition amongst researches. It suggests that in addition to 2D view-based matching, humans also apply 3D representations when recognizing faces. Moreover, the 3D face representations might be mediated by the face recognition experience amid the residential environment.

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# 3 3D Mental Representation in Face Recognition Ⅱ: 6th Grade Children Remain Immature in Face Viewpoint Transformation

## 3.1 Abstract

Children are immature in face recognition, particularly in face configural decoding. This study examines the developmental difference of face recognition in another mechanism, i.e. the viewpoint transformation processing. Sixth-grade children were instructed to match the one-tone black silhouettes to their corresponding front-view faces. This task involves sophisticated calculation in pictorial information, precise viewpoint transformation, and probable 3D face representation. The results show that though the performance is well above chance level in the recognition of familiar faces, it is at chance level in the recognition of unfamiliar faces. The results indicate that children, at least to the age of about 12, are still immature in face viewpoint transformation processing when recognizing faces.

## 3.2 Introduction

Face recognition is an important and sophisticated abilities that humans exhibit. Human indispensably need rapid face recognition for effective interpersonal interaction. It is not surprising that humans are able to process faces exceedingly early in life (Goren, Sarty, & Wu, 1975, Johnson, Dziurawiec, Ellis & Morton, 1991). However, despite the early employment of face recognition, this ability remains immature and continues to develop throughout childhood. It takes more than a decade for a child to reach the adult's level of face recognition expertise (Feinman, & Entwisle, 1976; Carey, 1992; Itler & Taylor, 2004a, 2004b; for a review see Chung & Thomson, 1995).

Face processing has been further distinguished into multiple processings. At least three of them have been deliberately explored to understand how humans decode the various kinds of information within faces. Component processing refers to an analytic process of deconstructing a face into a set of internal features (Sergent, 1984; Freire, Lee, & Symons, 2000; Freire & Lee, 2001; Schwaninger, Lobmaier, & Collishaw, 2002). Configural processing refers to a holistic process of taking into account the spatial relationship among facial features (Diamond & Carey, 1986; Bruce, Doyle, Dench & Buton, 1991; Rhodes, Brake & Atkinson, 1993; Freire et al, 2000; Mondloch, Grand, & Maurer, 2002). Holistic processing refers to treating faces as a gestalt regardless of the basis comprising the whole (Young, Hellawell, & Hay, 1987; Hole, 1994; Tanaka & Farah, 1993).

For decades, considerable effort has been made to explore the major aspects that can best explain the slow development in face recognition. A general consensus in the literature is that component and holistic processing develop faster than configural processing (Carey & Diamond, 1977, 1994; Freire & Lee, 2001; Mondloch, Grand & Maurer, 2002 Mondloch, Dobson, Parson, & Maurer, 2004). Children appear to rely primarily on featural and holistic information to recognize a face (Carey & Diamond, 1977; Mondloch, Grand & Maurer, 2002; Mondloch, Pathman, Le Grand, Maurer, & Schonen, 2007). They are much less sensitive to the subtle difference in the special relationship between facial features.

However, despite a large amount of research has been conducted to investigate the development of face recognition, this issue seems to focus mainly on the discussion regarding configural processing (Mondloch, Grand, & Maurer, 2002; Itler & Taylor, 2004b). Comparatively, less effort has been devoted to explore other aspects of developmental difference in face recognition e.g. how well can children perform the viewpoint transformation task in face recognition?

Recently, Davidenko (2007) developed a new methodology for face perception research. He proposed to use two-tone silhouettes as surrogate stimulus for front-view faces. He finds that the silhouettes provide enough information for gender, age, and attractiveness judgment. The most striking demonstration is the Experiment 5 of his research. He asked adult participants to match a front-view face to four possible silhouettes, or to match a silhouette to four possible front-view faces, i.e. 4 AFC (four alternative force choices). The results show that participants' performance (overall accuracy: 70.1%) was substantially higher than chance level (25%).

The viewpoint transformation competence that participants exhibit is especially notable considering that the silhouette representation of the unfamiliar faces are not available in memory. Meanwhile, the pictorial information such as texture and the intermediate views are not provided. In addition, the silhouette view is difficult to be generated from a front-view face. In the domain of computer vision, much effort has been made to develop the 3D face models (Vetter, 1998; Blanz & Vetter, 1999). Although one sole non-accidental 2D view might be sufficient for the construction of a computer 3D face model (Poggio, 1991; Poggio & Vetter, 1992; Beymer & Poggio, 1995), Poggio and Vetter (1992) suggest that the sole face view cannot be the exactly the front view. They stated: *one should avoid to use in the data base a model view which is a fixed point of the symmetry transformations (since the transformation of it generates an identical new view). In the case of faces, this implies that the model view in the data base should not be an exactly front-view* (Poggio & Vetter, 1992, *p*. 15). Basically, the front-view face is singular and a second view cannot be computed from it (Schyns & Bülthoff, 1993). Accordingly, the high performance that participants demonstrate in the experiment of Davidenko (2007) must involve complex representation which computer vision cannot simulate. This mental representation might involve sophisticated calculation of the distances between face features. It also needs to process the shading and shadow information contained in the face photographs to construct the shape of face features and the whole face (Bruce & Langton, 1994). In addition, it demands precise and highly proficient viewpoint transformation competence. Finally, it might also implicate explicit 3D face representation of the feature shape as well as the whole face (Tong & Nakayama, 1999). In other words, the complicated mental calculation and representation that being applied in the task might take years to fully develop before reaching a high proficient level.

This research aims to explore children's maturity of viewpoint transformation in face recognition. The 'face silhouette vs. front-view faces matching' paradigm developed by Davidenko (2007) was adopted. Three groups of six-graders with different extent to the face stimulus were recruited to participate in the experiment.

## 3.3 Experiment 4

### 3.3.1 Method

#### 3.3.1.1 Participants

Fifty nine sixth-grade students from three different groups participated in this experiment. Twenty of them (9 girls and 11 boys, mean age = 11.6 years) were recruited from class A and 21 of them (10 girls and 11 boys, mean age = 11.7 years) from class B in Wen-Shen primary school in Yunlin county in Taiwan. Another 16 students (9 girls and 7 boys, mean age = 12 years) were recruited from Chon-Wen primary school in Chiayi city in Taiwan. Based on the students' familiarity with the face stimuli used in this experiment, the three different participant groups were designated as ’same class’, ‘neighbor class’, and ‘novel class’, separately. It is worth noting that Wen-Shen primary school is a small school. Students of this school were randomly assigned to class A or B when they initially enrolled. Afterwards, students studied with the same classmates throughout their whole six-year primary education. Although in different classes, students of the same grade have many chances to encounter and interact with the students in their neighbor class in the small campus since there were only two classes in every grade. By contrast, Chon-Wen primary school locates in a different county and students being recruited as participants in ‘novel class’ group all claimed to be novel with the face stimuli used in the experiment.

#### 3.3.1.2 Materials

##### 3.3.1.2.1 Face stimuli

Gray-scale front views and right profile view photographs of the 21 participants in class B of the sixth-grade in Wen-Shen primary school and two adult male and female in National Chung-Chung University were taken using a Nikon Coolpix 3100. The photographs of these 25 persons were used as stimuli for compiling the test booklet used for this reseach. The right profile view photographs were transferred into one-tone black silhouette images using Photoimpact 10 software. The silhouettes were trimmed in four different ways: whole silhouette, head silhouette, front silhouette, and facial silhouette. Figure 11 displays examples of the stimuli. The whole silhouette included the top breast, neck, and the whole head as illustrated in Figure 11b. The head silhouette included just the head as illustrated in Figure 11c. The front silhouette included only the front part of the head as illustrated in Figure 11d. The facial silhouette included just the facial part image beneath the forehead illustrated in Figure 11e.

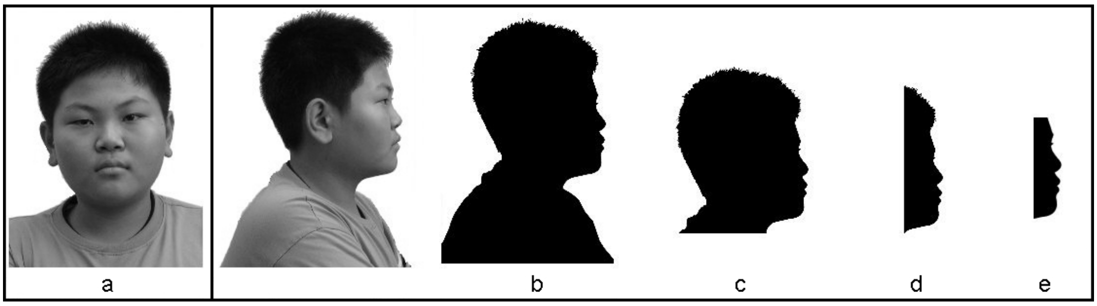


Figure 11. Examples of the stimuli used. a Front view (target face), b whole silhouette, c head silhouette, d front-head silhouette, and e facial-part silhouette.

### 3.3.1.2.2 Test booklets

Each booklet was composed of nine pages in A4 landscape format. One target page contained 25 grayscale front-view face images (as illustrated in Figure 1a) numbered from 1 to 25. The eight test pages had the same 5x5 grid in which one-tone silhouette stimuli were displayed as illustrated in Figure 12. The four types of one-tone

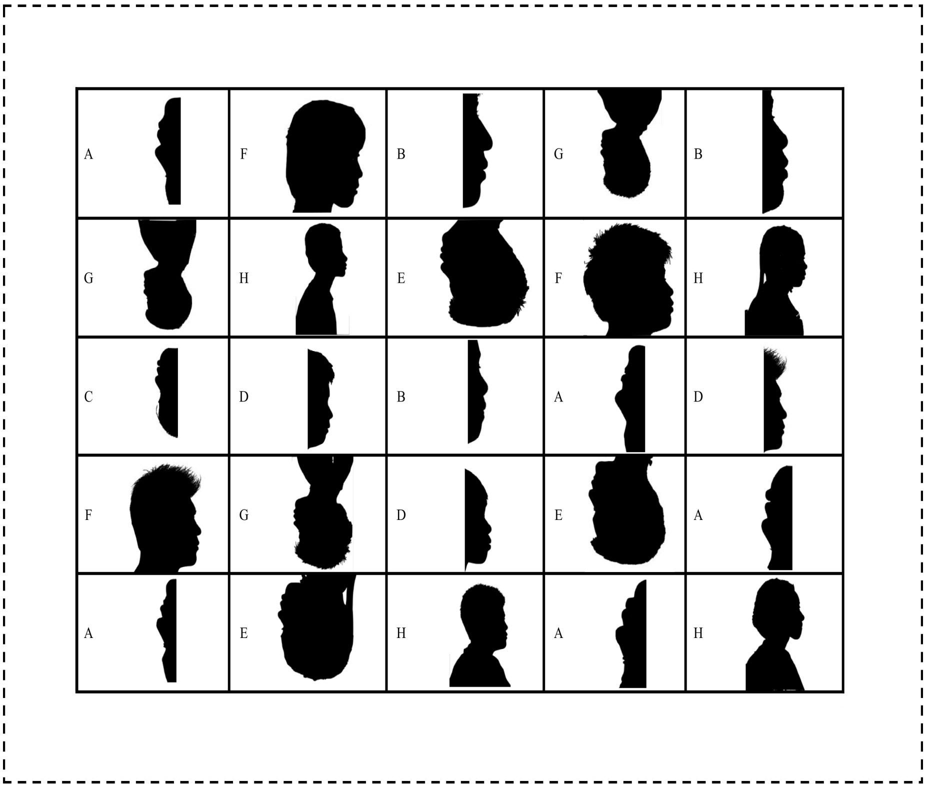


Figure 12. Example of one test page. The dashed line indicates the A4 size of the original test page.

silhouettes were shown in upright and inverted orientations resulting in 8 conditions (A to H). There were a total of 200 one-tone silhouette stimuli [25 (faces) x 8 (one-tone silhouette conditions] which were randomly distributed into the 25 cells in each of the eight test pages. The target page was placed above and the eight test pages were placed below the target page in a pile. Participants could turn over the test pages from the right to the left while the target page remained stationary.

3.3.1.3 Procedure

Participants were instructed to match the one tone silhouettes in the test pages to the gray-scale front-viewphotographs in the target page by writing down the corresponding number of the target face (from 1 to 25) inside the test face cell. Participants were encouraged to guess if they were not able to recognize the faces and were informed that there is no time constraint for completing the experiment. All participants completed the experiment within 30-50 minutes.

3.3.2 Results

Accuracy were subjected to a split plot ANOVA with orientation (upright vs. inverted) and silhouette type (as illustrated in Figure 1) as within-subjects factors,

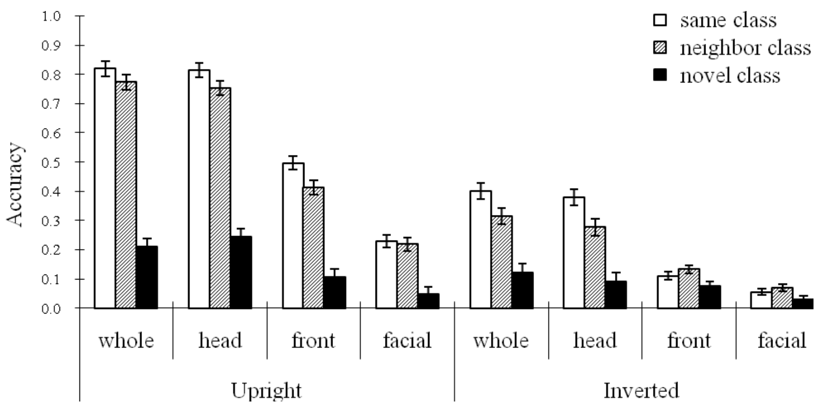

Figure 13. Accuracy in different conditions.

and group (same class, neighbor class, novel class) as between-subjects factor. Figure 13 displays means and standard errors of percent correct responses (accuracy) broken up by group, orientation, and silhouette type. Chance performance equals to 0.04. Bonferroni-corrected pair-wise comparisons were carried out for post hoc multiple comparisons when the ANOVA revealed significant effects.

The ANOVA revealed main effects of group, $F(2, 54) = 90.035$, $MSE = 3.577$, $p < .001$, orientation, $F(1, 54) = 729.774$, $MSE = 7.345$, $p < .001$, and silhouette type, $F(3, 162) = 519.683$, $MSE = 2.934$, $p < .001$. Bonferroni-corrected pair-wise comparisons revealed that the performance of the same class group was equivalent to that of the neighbor class group ($p = .147$). Both of the two groups perform better than the novel class group (*ps* < .001). Performance for upright stimuli was better than for inverted stimuli, i.e. the inversion effect was demonstrated (Yin, 1969; for reviews see Valentine 1988). Finally, Bonferroni-corrected pair-wise comparisons revealed that performance was equivalent between whole silhouette and head silhouette conditions ($p = .66$). Both of them were better than the performance in front silhouette condition (*ps* < .001). And all of them were significantly better than performance in the facial silhouette condition (*ps* < .001). The ANOVA also revealed a significant interaction between group and orientation, $F(2, 54) = 86.515$, $MSE = .871$, $p < .001$, group and silhouette type, $F(6, 162) = 47.756$, $MSE = .270$, $p < .001$, and orientation and silhouette type, $F(2.2, 117.7$[1]$) = 52.216$, $MSE = .454$, $p < .001$. The three-way interaction was also significant, $F(6, 162) = 5.742$, $MSE = .036$, $p < .001$. To clarify the source of three-way interaction, separated ANOVAs were conducted for upright and inverted conditions.

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[1] In all analyses of this study, if Mauchly,s (1940) test of sphericity showed a significant deviance ($\alpha < 0.25$) from equicorrection for a repeated factor or for a combination of factors including at least one repeat factor, Greenhouse and Geisser's (1959) Epsilon was used to adjust the degrees of freedom for the averaged tests of significance.

#### 3.3.2.1 <u>Upright</u>

The ANOVA for upright trials revealed main effects of group (same, neighbor, and novel class), $F(2, 54) = 129.632$, $MSE = 3.978$, $p < .001$, and silhouette type, $F(3, 162) = 449.183$, $MSE = 2.588$, $p < .001$. The interaction between group × silhouette type was also significant, $F(6, 162) = 36.204$, $MSE = .209$, $p < .001$. For main effect of group, Bonferroni-corrected pair-wise comparisons revealed that the performance was comparable between the same class group and the neighbor class group ($p = .211$).The performance of these two groups was significantly better than that of the novel class group (*ps* < .001). The main effect of silhouette type shows that performance in the whole silhouette and the head silhouette conditions were equivalent ($p > 0.9$), while both of them were significantly better than performance in the front silhouette condition (*ps* < .001). Performance in these three types was significantly better than the performance in the facial silhouette condition (*ps*< .001). For the group × silhouette type interaction, analysis of simple main effects revealed that for front silhouette, the difference between the same class group and neighbor class group was marginally significant (*ps* < .051). However, for the other three silhouette types the performance between same class and neighbor class groups were equivalent (*ps* > .187).

#### 3.3.2.2 <u>Inverted</u>

The ANOVA for inverted trials revealed main effects of group, $F(2, 54) = 24.571$, $MSE = .469$, $p < .001$, and silhouette type, $F(2.1, 111.8) = 108.95$, $MSE = .979$, $p < .001$. The interaction between group and silhouette type was also significant, $F(6, 162) = 15.684$, $MSE = .097$, $p < .001$. For the main effect of class, Bonferroni-corrected pair-wise comparisons revealed that performance was comparable between the same class group and the neighbor class group ($p = .24$). Performance of these two groups was better than that of the novel class group ($ps < .001$). For the main effect of silhouette type, performance in the whole silhouette and the head silhouette conditions were comparable ($p > .1$), while both of them were significantly better than that in the front silhouette condition ($ps < .001$). And all of them were significantly better than the performance in the facial silhouette condition ($ps < .001$). For the class × silhouette type interaction, analysis of simple main effects using Bonferroni-corrected revealed that pair-wise comparisons between different groups were all significant for the head silhouette type ($ps < .038$). However, performance of the same class group and neighbor class groups were comparable in the other three silhouette types ($ps > .09$).

3.3.2.3 Inversion effect

Two tailed T-tests were conducted for upright vs. inverted stimuli broken up by groups and silhouette types to examine the inversion effect. Among the 12 conditions (3 groups × 4 types), except for conditions of recognizing the front silhouette ($p = .111$) and facial silhouette ($p = .276$) for the novel class group, all the other conditions demonstrated inversion effects ($ps < .01$)

3.3.2.4 Tests against chance performance

Two tailed T-tests were conducted for the 24 conditions (3 classes × 4 types× 2 orientations) to examine whether performance was better than chance. Except for the recognition of inverted facial silhouette for the same class group ($p < .134$), and the recognition of upright ($p < .549$) and inverted facial part silhouette ($p < .216$) for the novel class group, performance in all other conditions was higher than chance level ($ps < .04$).

### 3.3.3 Discussion

Research reveals that the face configural processing develops much slower than feature or holistic processing. This study explores the developmental difference of face recognition in a different mechanism, i.e. the viewpoint transformation processing. It has been demonstrated that adults can readily match a front-view face to their corresponding silhouette or vice versa. This processing requires complex calculation and representation of the 3D information embedded in faces. The current study examines the maturity of this viewpoint transformation processing. Results show that 6$^{th}$-grade children were still ineffective in viewpoint transformation processing when they were required to recognize unfamiliar faces from only the facial part.

Performance was comparable between participants from same class group and neighbor class group, and performance of these two groups was significantly better than that of the novel class group. For students from either same class or neighbor class group, the performance was mediated by the information contained in the silhouettes. Performance significantly declined when the shape of the head and the hairstyle cues were cropped out. However, despite that the decline is conspicius, the performance was still much better than chance level when only the subtle facial curve was retained in silhouettes. These results suggest that with the extensive experience in the recognition of familiar faces, participants might have stored the profile view in memory and develop robust profile mental representation for familiar faces. However, this representation might mainly base on the shape of the head and the hairstyle. The contribution from the sophisticated facial outline curve was relatively low. Moreover, this profile representation was largely constrained to the upright orientation of which faces were normally encoded. For participants from novel class, although the performance was higher than chance level in the recognition of whole silhouette, head silhouette, and front silhouette, it was at chance level in the recognition of facial silhouette. Performance in the recognition of facial silhouette for novel class provides a crucial evaluation to assess whether participants can apply the viewpoint transformation processing. For participants from novel class, the profile views of the target faces were not available for them. Meanwhile, view-based calculation such as linear interpolation between views (Poggio & Edelman, 1990), multiple views plus transformations (Tarr & Pinker, 1989) or linear combination of views (Ullman & Basri, 1991) were not applicable because only one singular view was provided.

In the experiment of Davidenko (2007), the face silhouettes that participants were required to match were identical to the facial silhouette in current experiment. In addition, the face stimuli were novel to the participants. The condition in their experiment is exactly identical to the condition in the recognition of facial silhouette for students from novel class group in current study. The adult participants exhibit high proficiency in the viewpoint transformation task in the study of Davidenko (2007). By contrast, children from novel class group participants were completely incapable of solving this task in current study. It suggests that participants from novel class simply rely on the non-facial external information to recognize the faces. They were unable to process the 3D information embedded within the faces. As discussed previously, participants might need the deployment of multiple mechanisms to accomplish this task. It includes recovering the 3D features from shading and shadow information (Bruce & Langton, 1994), calculation of the distances between face features, precision of the viewpoint transformation, etc. This competence apparently takes years to reach proficiency.

In sum, results of this study indicate that in addition to the configural processing, the viewpoint transformation skill in face recognition also develops substantially slow. It is still far from proficient in the early adolescence. The results of this research provide notable insight to the inspection of developmental difference in face recognition. Apparently, face recognition involves divergent and complicated mechanisms. The slow development in face recognition might be due not only to the deficit in configural processing but also to the immaturity in other associated cognitive skills such as the capacity of transforming the face view from a different viewpoint.

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# 4 2D Mental Representation in Face Recognition: Face Inversion Effect Emerges under Critical Configural Discrepancy

## 4.1 Abstract

Configural processing has been considered as the major contributor of the face inversion effect (FIE) in face recognition. However, most of the previous researches obtain the FIE in only one specific ratio of the configural alteration. It remains unclear whether the ratio of the configural alteration itself can mediate the occurrence of the FIE. This paper aims to clarify this issue by manipulating the configural information parametrically in 6 different ratios, ranging from 4% to 24%. Participants were asked to judge whether a pair of faces were entirely identical or different. The paired faces to be compared were presented either simultaneously (Experiment 1) or sequentially (Experiment 2). Both experiments revealed that the FIE was observed only when the configural alteration was in the intermediate ratios. These results indicate that even thought the FIE has been frequently adopted as an index to examine the underlying mechanism of face processing, the emergence of the FIE is not robust in any arbitrary configural alteration but is susceptible to the ratio of the alteration.

## 4.2 Introduction

As social animals, human beings are surrounded in their lives by innumerable faces and are able to recognize faces extremely quickly, i.e. 34 ms is sufficient for recognizing familiar faces (Carbon, Schweinberger, Kaufmann, & Leder, 2005). Humans can even identify faces before paying specific attention to them (Reddy, Wilken, & Koch, 2004; Reinitz, Morrissey, & Demb, 1994). Face recognition is probably the most sophisticated ability that human beings exhibit, especially considering the fact that all faces are composed of relatively few constituent elements in an identical configuration. However, despite the extreme human capability of face processing, accumulated research has found that face recognition is disproportionately impaired by inversion when compared to the recognition of other objects. The impairment of face recognition in inverted faces is always referred to as the face inversion effect (FIE). The emergence of FIE implies that upright and inverted faces are processed differently. The occurrence of FIE is considered as important evidence to support the notion that upright and inverted faces are processed differently.

In the domain of face recognition, three kinds of distinct processing have been thoroughly investigated that collectively would define the ability of face recognition (Mondloch, Grand, & Maurer, 2002). First, component or featural processing refers to an analytic process of decomposing a face into a set of internal features (Sergent, 1984; Freire, Lee, & Symons, 2000; Freire & Lee, 2001; Hayward, Rhodes, & Schwaninger, 2008). Second, configural processing refers to the coding of a spatial relationship among facial features (Rhodes, Brake, & Atkinson, 1993; Freire et al, 2000; Schwaninger, Lobmaier, & Collishaw, 2002; Mondloch et al., 2002; Leder, & Carbon, 2006). Third, holistic processing refers to treating faces as a gestalt regardless of the basis comprising the whole (Young, Hellawell, & Hay, 1987; Hole, 1994; Tanaka & Farah, 1993; Leder & Carbon, 2005; Richler, Gauthier, Wenger, & Palmeri, 2008). Schwaninger and his colleagues (Schwaninger, Lobmaier, & Collishaw, 2002; Schwaninger, Wallraven, & Bülthoff, 2004; Wallraven, Schwaninger, & Bülthoff, 2005; Schwaninger, Lobmaier, Wallraven, & Collishaw, 2009) propose a computational model of face representation. They suggest that featural and configural informations are represented separately in the early stage of face recognition. Afterwards, these two kinds of representations were integrated to a holistic face representation.

Considerable evidence suggests that face configural processing might be the major contributor for the occurrence of FIE. FIE can be easily observed in configural alteration but not in component change (Diamond & Carey, 1986; Bartlett & Searcy, 1993; Rhodes, Brake, & Atkinson, 1993; Tanaka & Farah, 1993; Searcy & Bartlett, 1996; Tanaka & Sengco, 1997; Leder & Bruce, 1998, 2000; Schwaninger & Mast, 2005; Leder, & Carbon, 2006). Although mild FIE was obtained occasionally, the results might be due to accompanied configural change when face component was replaced. Murray, Yong, and Gillian (2000) provided another piece of evidence for the inversion effect from rating faces for bizarreness. They found that bizarreness rating shows discontinuity for Thatcherized faces (Thompson, 1980) and configuration distortion, but not for component distortion. Their results suggest a qualitative difference between the processing of upright and inverted faces. Specifically, for inverted faces, the encoding of configural information was impaired disproportionately comparing to the encoding of feature information. However, in an ERP (event-related potentials) research, Carbon, Schweinberger, Kaufmann, and Leder (2005) found that the magnitude of N170 between inverted Thatcherized faces and inverted original faces is different. This result suggests that inverted Thatcherized faces are processed differently compared to inverted normal faces.

Empirically, FIE can easily be replicated in face research and has been widely adopted as index to examine many important issues in face recognition research. For example, it has been found that inversion costs are not equivalent for recognizing faces of different races (Rhode, Tan, Brake, & Taylor, 1989; Rhode, Brake, &

Winkler, 2006), for distinguishing objects vs. faces ( Yin, 1969; Tanaka, & Farah, 1993; Farah, Wilson, Drain, & Tanaka, 1998; Cooper, & Brooks, 2004) or for identifying faces by participants of different ages (Carey & Diamond, 1977; Chung & Thomson, 1995; Mondloch, Grand, & Maurer, 2002; Itler & Taylor, 2004a, 2004b). In others words, many researchers have based their conclusion on the presence or absence of FIE. However, in most of the previous researches, analyses were conducted just to demonstrate whether or not inversion effect was observed in a particular condition, or whether or not inversion effects were equal under different conditions. Therefore, most of the previous researches obtain the FIE in only one specific ratio of the configural alteration. The factors that might affect the emergence or magnitude of FIE are seldom examined. Although Barton, Keenan, and Bass (2001) and Rhodes, Hayward, and Winkler (2006) ever parametrically manipulates the configural information in their researches. However, these researches share some drawbacks which make it difficult to interpret the influence of ratio alteration on the emergence of FIE.

Rhodes, Hayward, and Winkler (2006) applied a novel method of configural alteration in their research. They artificially created a continuum to manipulate the extent of configural alteration. In this manner, a features-in face was created by moving the eyes in and down for 8 pixels and moving the mouth up for 8 pixels. A features-out face was created by moving the eyes out and up for 8 pixels and moving the mouth down for 8 pixels. The configural alteration was manipulated by adjusting the ratio between features-in face (0%) and features-out face (100%). However, moving absolute fixed pixel in different faces apparently ignore the variable size of original faces. The fixed quantity of pixel movement on different faces will inevitably lead to inconsistent ratio of configural alteration in reference to the original faces. Moreover, this method will make it difficult to reflect the ratio of configural alteration on the faces. For example, people might expect that 50% change will lead to a sizeable alteration on configural information. However, in their method, 50% means the average between features-in face (0%) and features-out face (100%) and thus surprisingly represent the original face without any configural alteration. In addition, the meaning of the number on the configural alteration might also lead to a considerable discrepancy of size interpretation. For example, the 10%, 20%, 30%, 40% of configural alterations actually represent movement for 1.6, 3.2, 4.8, and 6.4 pixels separately. The numbers on the ratio of configural alteration highly exaggerate the extent of configural alteration because all the faces were standardized to have a pupil separation for 80 pixels. Although Barton et al (2001) did not adopt the continuum framework, they also used a similar method of moving fixed quantity of pixel on different faces. Eventually, these methods make it difficult to reflect the ratio of configural alteration on the faces. Moreover, Barton et al (2001) aimed to compare the difference between the movement and color of different features (eye and mouth), whereas Rhodes et al (2006) aimed to explore the race difference of configural and component processing. Both studies did not directly compare the magnitude of inversion effect under different extent of configural alteration in their papers. Therefore, the issue concerning how FIE is influenced by different extent of configural alteration was not elaborately addressed in their researches.

In other words, it remains unclear how the ratio of the configural alteration itself can mediate the occurrence of the FIE. The current research aims to clarify whether the ratio of the configural alteration itself can be a factor to mediate the occurrence of FIE. In the current experiment, the face configural information is altered parametrically in six different ratios, ranging from 4% to 24% with an interval scale of 4 %. I examine whether the FIE can be obtained in any arbitrary ratio or is limited to some specific ratios. In the current research, face configural information was altered in proportion to the original face. The original inter-eyes and nose-mouth distance was measured and the ratio change was based on the original distance. This method can appropriately avoid the problematic interpretation in the study of Barton et al (2001) and Rhodes et al (2006).

## 4.3 Experiment 5

### 4.3.1 Method

#### 4.3.1.1 Participants

Twenty European students (12 male, mean age 25.05 years) at the University of Zurich participated in the experiment to fulfill a requirement of their psychology course.

#### 4.3.1.2 Materials

Sixteen faces balanced by gender and race (European vs. Asian) were randomly selected from a face database built up by the VICOREG research team at the University of Zurich. In each case, the distance between the two eyes and the distance between the lowest part of the nose and the topmost part of the upper lip were

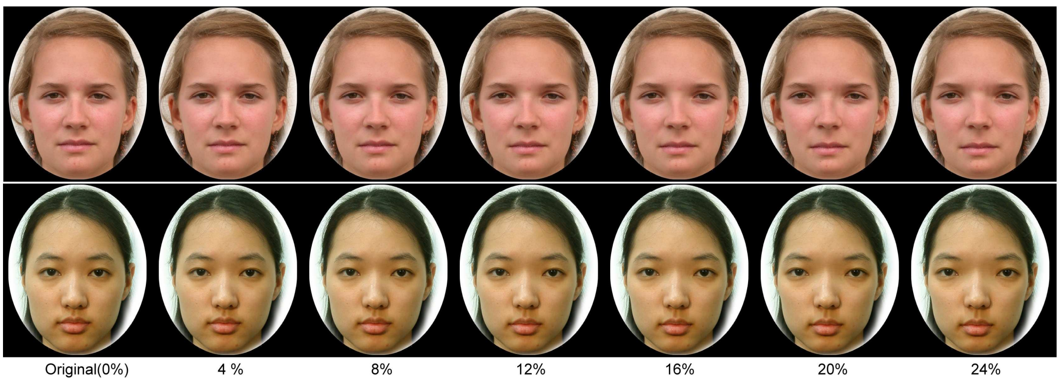


Figure 14. Examples of the different ratios of configural alteration in an Asian and an European female faces.

measured. The face configuration was altered by moving the paired eyes (with the eyebrow) apart and moving the mouth downwards. The magnitude of alteration in face configuration was manipulated in six different ratios, i.e. 4%, 8%, 12%, 16%, 20% and 24%. Each of the faces was positioned inside an elliptical shape. Figure 14 gives examples of the different ratios of configural alteration in an Asian and an European female faces.

4.3.1.3 Procedure

The experiment was based on a four-factor design with orientation (upright vs. inverted), identity (same vs. different), race (Caucasian vs. Asian faces), and configural alteration ratios (4%, 8%, 12%, 16%, 20%, and 24%) as variable factors. For each trial, a pair of faces representing the same person were presented on the 17inches LCD monitor without time constraint. The presentation of the pair of faces lasted until a response was made. I adopt the self-paced paradigm to make sure that participants have sufficient time to accomplish the task because no prior knowledge can be consulted regarding how performance will be when configural information is altered subtly e.g. only 4 %. Basically, Experiment 1 is a probe experiment which aims to examine the configural processing in various ratio of configural alteration with no intention to bear on the memory processes (cf. Perrett, Oram, & Ashbridge, 1999). The paired faces were always presented in the same orientation, i.e. both upright or both inverted. Partici-

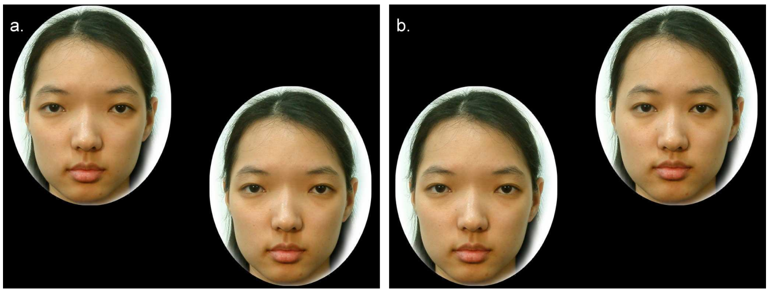


Figure 15. a: Configurally-same trial (both faces were altered in their configural information by 20 %; b: Configurally-different trial (upper-right face was the original face (0%) and lower-left face was the 20% configurally-altered face.

pants were not fixed in their head and the viewing distance was about 50 cm. The elliptical shape is about 14 cm wide and 16 cm long on the 17inches LCD (Liquid Crystal Display) monitor and subtends a visual angle of about 15.6° and 17.7° separately. One of the paired faces was randomly assigned to one of four positions (top-right, bottom-right, top-left and bottom-left), while the other was always placed in the diagonally opposite position, as displayed in Figures 2 and 3. In configurally-different trials, an original face was presented with one of the ly-altered versions of it. In configurally-same cases, the paired faces were identical images that altered the original face by same ratio; thus, two depictions of an original face had the configural information altered by, for example, 12% in both cases. The purpose of adopting configurally-altered faces (both configurally-altered to the same extent) instead of the original faces (both original faces) as the configurally-same trials was twofold. Firstly, it eliminated any disproportionate learning effect for the original faces compared to the configurally-altered faces; for example, if the original faces had been used in all the configurally-same conditions, the original faces would have been viewed 18 times[2] more often than any configurally-altered face. Second, it provides a rationale to convert the accuracy data into *d'* score in different ratio alteration for further analysis. In the configurally-different condition, one face is the original one (0% configural alteration) and the other is a configurally-altered face that could be altered in one of the six different ratios. Figure 2 illustrated examples of the same and different trials in 24 % configural alteration. Twelve practice trials balanced in orientation, identity, ratios and face race were

[2] For example, in the trials of 4% configurally-altered faces, two original faces will be presented in the configurally-same trial, while one original face and one configurally-altered face will be presented in the configurally-different trial. As a result, there are three original faces and only one configurally-altered face. The same situation also occurs in the configurally-altered trials at 8%, 12%, 16%, 20%, and 24%. In the end, the original face will have been presented 18 times, whereas each face with a different extent of configural alteration will have been presented only once.

provided for each participant prior to the formal experiment. The images in the practice trials were not shown again in the formal experimental trials. There were 384 trials (2 orientations × 2 identities × 6 ratios × 2 races × 8 examples) presented randomly for each participant in the formal experimental section. Participants were instructed to judge, without time constraint, whether the paired faces presented simultaneously were entirely identical or different. After participants pressed one of the prior-designated keys, an image appeared instructing participants to press any key to initiate the next trial.

### 4.3.2 Results

The percentage of correct responses in configurally-different trials (response 'different' when the configuration was different) was treated as the hit rate. The percentage of incorrect responses in configurally-same trials (response 'different' when the configuration was identical) was treated as false alarms. The data were then converted to *d*' score by the following equation: *d*' = z(hits) – z(FA) to take into account the participant's response bias.

#### 4.3.2.1 *d*' score

Figure 16 displays means and standard error of the *d*' score divided by orientation and ratio. The data were subjected to a three-factor analysis of variance (ANOVA) with orientation, face race, and ratio as within-

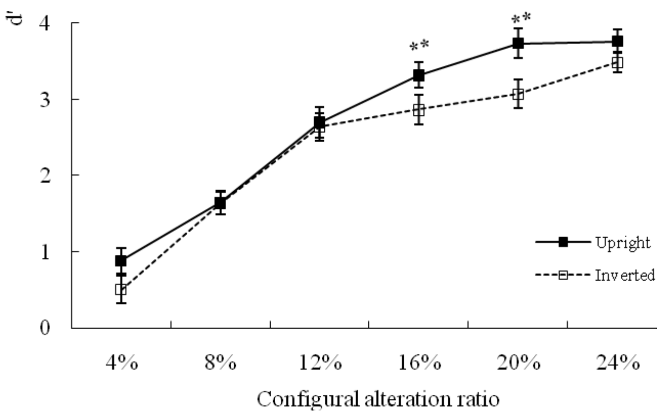


Figure 16. The mean D prime score in configural alteration with different ratios of Exp. 5

participants factors. A Bonferroni posteriori pair-wise comparison was conducted when the analysis of variance revealed significant differences between conditions.

The repeated-measure ANOVA revealed the main effects of orientation, $F(1,19) = 20.90$, $MSE = 11.34$, $p < .001$, and ratio, F(3.29[3], 62.63) = 128.128, $MSE = 156.51$, $p < .001$. The inversion effect was replicated. Overall, performance in the recognition of upright faces was better than that of inverted faces. For the main effect of ratio, posterior comparison revealed that all the pair-wise comparisons between different ratios were significant (Bonferroni, *p*s < .001) except for the comparisons between 12% and 16% (Bonferroni, $p = .12$), 16% and 20% (Bonferroni, $p = .11$), and 20% and 24% (Bonferroni, $p = .19$). The ANOVA also revealed significant two-way interaction between face race and ratio, $F(5, 95) = 2.40$, $MSE = 1.71$, $p < .042$. Simple main effect analysis revealed that performances were comparable between Asian and European faces in configural alterations of 4%, 8%, 12%, and 16% (*p*s > .152), whereas performance in the recognition of Asian faces was better than that for European faces in configural alterations of 20% and 24% (*p*s < .047). No further main effects or interaction effects were found.

### 4.3.2.2 Face inversion effect

The experiment aims to explore whether inversion effect can be demonstrated in any arbitrary ratio of configural alteration. To this purpose, Iconducted separate *t*-tests on the performance of upright vs. inverted conditions in different ratios to examine the fluctuation of FIE in different ratios of configural alteration. As can be seen from Figure 3, the inversion effect was significant only in the configural alterations of 16% and 20% (*p*s < .01).

[3] In all analyses of this study, if Mauchly's (1940) test of sphericity showed a significant deviance from equicorrection for a repeated factor or for a combination of factors including at least one repeat factor, Greenhouse and Geisser's (1959) Epsilon was used to adjust the degrees of freedom for the averaged tests of significance.

### 4.3.3 Discussion

The results show that configural processing systematically improved with increasing degrees of configural alteration. This pattern was demonstrated in both upright and inverted faces. The inversion effect emerges only in the intermediate ratios of configural alteration, but not in the considerable or subtle configural alteration. Specifically, there is a critical configural discrepancy for the emergence of the FIE. These results suggest that the ratio of the configural alteration indeed mediate the occurrence of FIE. FIE is not robust in any arbitrary configural alteration but is susceptible to the ratio of the configural alteration.

## 4.4 Experiment 6

The simultaneous presentation of faces and unlimited duration in Experiment 1 might encourage participants to compare the faces feature by feature. Hole (1994) suggested that short exposure duration might force participants to process the face as a whole, whereas long exposure duration might encourage participants to use a feature-by feature matching strategy. In information processing theories, it is proposed that visual information is processed from coarse-to-fine (Parker & Costen, 1999; Parker, Lishman & Hughes, 1992, 1996; Schyns & Gosselin, 2003; Schyns & Oliva, 1994). The coarse visual information refers to the global impression of the overall information, specifically the holistic analysis; whereas the fine visual information refers to the elaborated analysis of local information. It is also found that the configural information is mainly conveyed by low spatial frequency while feature information is mainly conveyed by low spatial frequency (Schwaninger, Wallraven, & Bülthoff, 2004; Goffaux, Hault, Michel, Vuong, & Rossion, 2005;

Goffaux, & Rossion, 2006). Accordingly, the holistic processing precedes the feature processing (Goffaux, & Rossion, 2006). In Experiment 2, the paired faces were presented sequentially. The first face was presented for only 500 ms. The short presentation of the first faces was adopted twofold. First, to encourage the processing the faces holistically and elicit mainly the configural processing. Second, to reduce the application of the feature by feature matching strategy.

### 4.4.1 Method

#### 4.4.1.1 Participants

Twenty European participants (9 male, mean ages 24.5) were recruited from the University of Zurich. Participants received either a monetary reward or credit points to fulfill the psychological course requirement.

#### 4.4.1.2 Materials

The facial stimuli and the configural alterations were identical to those used in Experiment 1.

#### 4.4.1.3 Procedure

The experimental design was identical to that in Experiment 1. However, the paired faces to be compared were presented sequentially. During each trial, a fixation cross was presented in the center for 500 ms. Then the first face was presented on the screen for 500ms. Afterwards, a mask covered the whole stimulus area for 500 ms. Then, the second face was presented on the screen for 500 ms. After the end of the presentation of the second face, a question image which instructed participants to press the corresponding key (‘same’ or ‘different’) was presented on the screen with no time limit. After participants had responded, the question image disappeared and a further image appeared instructing participants to press any key to initiate the next trial. Among the 384 trials, half were configurally-same and the other half configurally-different. For configurally-different trials, the sequence of presentation (original face versus configurally-altered face) was balanced; thus, in half of these trials, the original faces were presented first, whereas in the other half the configurally-altered faces were presented first.

### 4.4.2 Results

#### 4.4.2.1 *d’* score

The method of analysis in Experiment 2 was identical to that in Experiment 1. The data were converted to *d’* score and were subjected to a three-factor analysis of variance (ANOVA) with orientation, face race, and ratio as within-participants factors. A Bonferroni posteriori pair-wise comparison was conducted when the analysis of variance revealed significant differences between conditions. Figure 17 displays means and standard error of the d’ score divided by orientation and ratio in Experiment 6. The repeated-measure ANOVA revealed the main effects of orientation, F(1,19) = 11.66, MSE = 15.76, $p < .001$, and ratio, F(5, 95) = 29.08, MSE = 31.08, $p < .001$. The inversion effect was again replicated. For the main effect of ratio, posterior comparison revealed that performance in 16%, 20%, and 24% ratios was

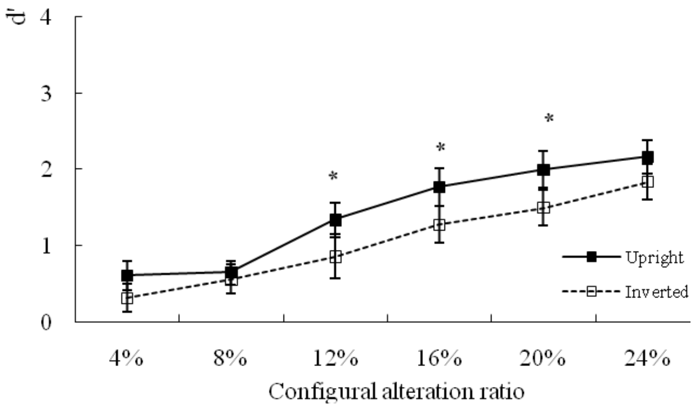

Figure 17. The mean D prime score in configural alteration with different ratios of Exp. 6.

higher than that in 4%, 8%, and 12%, and performance at 24% was higher than at 16% ($p$s < .037). No further main effects or interaction effects were found.

#### 4.4.2.2 Face inversion effect

The inversion effect was significant only in the 12%, 16%, and 20% of configural alterations ($p$s < .05).

### 4.4.3 Discussion

Although overall performance declined when the paired faces were presented sequentially, the pattern revealed in Experiment 1 was replicated in Experiment 2. Performance improved with the increasing ratio of configural alteration. This trend was evident in both upright and inverted faces. In addition, similar to the results in Experiment 1, the inversion effect emerges only in the intermediate range of configural alteration, but not in the substantial or subtle configural alterations.

## 4.5 General Discussion

In face recognition research, FIE serves as an important index to examine various issues regarding face processing. Many arguments are based on the presence or absence of FIE. However, the FIE was often demonstrated in only one specific ratio of configural alteration in previous research. The ratio of the configural alteration was seldom considered as a factor to mediate the emergence of FIE. It, therefore, remains unclear whether the ratio of the configural alteration can be a factor to mediate the occurrence of the FIE. In the current research, Ialtered the configural alteration parametrically in six different ratios and examined whether the FIE can be obtained in any arbitrary ratio or is limited to some specific ratios. Both experiments reveal that the FIE emerges only under critical discrepancy of face configural information. In addition, performance improves systematically with increasing ratio of face configural alteration in either upright or inverted faces. These results suggest that the ratio of the configral alteration plays an important role to mediate the occurrence of the FIE. The FIE is not robust in any arbitrary configural alteration but is susceptible to the ratio of configural alteration. Accordingly, the arguments which are based on FIE should be interpreted cautiously because the FIE could be contaminated by the ratio of the configural alteration. This caution is in agreement with Ellis (1975) and Goldstein and Chance (1981) who casted doubt on the evidence derived from FIE.

It is interesting that, in both experiments, FIE emerges only in some critical configural discrepancy which is located in the intermediate ratio of the configural alteration at around 12% to 20%. A non-linear increasing difference between performance of upright and inverted faces was demonstrated robustly. The differences of performance between processing upright and inverted faces reach a maximal at 16% and 20% of configural alteration and a minimum at 8% and 24% of configural alteration. Here I propose possible explanations from two different perspectives. First, the pattern might be due to the natural limitation of configural variation. The intermediate extent of configural alteration could represent an acceptable range for configural variation in natural limitation. Configural alteration which exceeds this acceptable range might make faces look unusual and become salient. The abnormal spatial arrangement of features makes it easy to detect the configural difference in either upright or inverted orientation. Second, the non-linear increasing difference between performance of upright and inverted faces might arise from different criterions for detecting the discrepancy of configural information in different orientations. In other words, humans might foster a more sensitive system for detecting the discrepancy of configural information in upright faces than in inverted faces. This is not surprising as humans are only expertise in recognizing upright faces. The FIE did not emerge in subtle alteration of configural information might reflect the fact that subtle configural alteration makes discrimination difficult in both upright and inverted faces. As a result, the processing of face configural information is comparable between upright and inverted faces. It has been found that although humans are sensitive to the configural information, they do not assess the distances of inter-eyes or distance between eye and mouth precisely. On the contrary, humans distort the distance of inter-eyes, or distance between eye and mouth to a surprising extent e.g. overestimation the eye-mouth distance for 41% and inter-eye distance for 16% in either upright or inverted orientation (Schwaninger, Ryf, & Hofer, 2003). The imprecise perception of distance between face features might deteriorate the discrimination of configural information for subtle alteration in either upright or inverted orientations. Similar results can be found in the research of Rhodes et al (2006). Despite Rhodes et al (2006) did not report the fluctuation of FIE in different extent of configural alteration, the figure they provided clearly shows a substantial reduction of FIE with the decrease of pixel movement.

The FIE also vanishes in sizable configural alterations, which might reflect the fact that sizable configural alteration can reach the perceptual criteria for detecting the configural discrepancy in both upright and inverted faces. Finally, for intermediate ratios of configural alteration, the configural alteration can reach the perceptual criteria of detecting the configural discrepancy in upright faces more easily than in inverted faces. As a result, the FIE emerges under the unequal proficiency of configural processing in different orientations.

The current results seem to contradict to some arguments which claim that humans are inaccessible to the configural information in inverted faces (Yin, 1969; Sergent, 1984; Diamond, & Carey, 1986). The results of current study show that configural information in inverted faces is still extractable. Moreover, configural processing in inverted faces also improves gradually with increasing amounts of configural alteration. These results are in accordance with those of Barton, Keenan, and Bass (2001) and Rhodes, Hayward, and Winkler (2006). As mentioned in the introduction section, despite the FIE was not directly examined in these researches, these researches also manipulated the extent of configural alteration. A highly identical pattern can be observed from the figures in these researches. Both researches show that the performance improves gradually with the increase of pixel movement in either upright or inverted orientations. Accordingly, configural processing in inverted faces is impaired in its sensitivity, but not the capability of extracting the face configural information. The difference in the configural processing of upright versus inverted faces might not be an ‘all-or-none’ issue, but rather one concerning the extent of the efficiency of configural processing. As proposed by Sekuler, Gaspar, God, and Bennett (2004), the primary difference between the processing of upright and inverted faces might be quantitative rather than qualitative. Information is extracted more efficiently in upright than in inverted faces. The advantage in processing upright faces may simply be a by-product of relative expertise levels because humans have more experience in recognizing upright faces than inverted faces.

The findings of the current research seem also contradictive to the conclusion of the studies from Thatcherized faces (Thompson, 1980; Stuerzel & Spillmann, 2000; Carbon, Grüter, Weber, & Lueschow, 2007). Evidence from Thatcherized face studies suggests that there might be a qualitative difference between the processing of upright and inverted faces. However, in this paper, I define the configural processing as processing the coordinate relations between face features, i.e. the precise spatial distance between features without involvement of component processing (Freire, Lee, & Symons, 2000; Mondloch, Grand, & Maurer, 2002; Cooper, & Brooks, 2004; Schwaninger, & Mast, 2005; Leder, & Carbon, 2006). The Thatcherized face (Thompson, 1980) which inverts the eyes and mouth in a normal face might involve in both component and configural processing. The combination of component and configural processing might render the processing of Thatcherized face much similar to the holistic processing (Schwaninger, Wallraven, & Bülthoff, 2004). In other words, as configural and holistic processing involve different mechanisms, the notion that there is a quantitative difference between the processing of upright and inverted faces can only be restricted to the processing of configural information.

Another issue which is worth addressing is the disappearance of the other-race effect in both experiments. It has been proposed that it is easier for people to distinguish between faces of their own race than between those of another (see Meissner & Brigham, 2001 for a review). Further research indicates that the other-race effect in face recognition might be due to the impairment of extracting the component information, holistic information, or configural information in other-race faces (Michel, Caldara, & Rossion, 2006; Rhodes, Hayward, & Winkler, 2006; Hayward, Rhodes, & Schwaninger, 2008). However, in those experiments, participants were required to assess whether the faces differed in either holistic, component, or configural information throughout the whole task. In other words, the component or configural processing was not enhanced since participants had to pay attention to a variety of different information. Instead, in the current study, participants were encouraged to apply only configural processing during the whole task. In addition, the configural information was systematically altered to different extents. This might also have enhanced participants' configural processing during the task. The results of Experiment 2 show that participants' performances were comparable in discriminating Asian faces and Caucasian faces under this paradigm. These results were not surprising, because the other-race effect was not always replicated (Tanaka, Kiefer, & Bukach, 2004; Bothwell, Brigham, & Malpass, 1989). However, Experiment 1 produced an unexpected result, revealing that Caucasian participants performed better in recognizing Asian rather than Caucasian faces in configural alterations of 20% and 24%. Although the opposite other-race effect seems to be surprising, these results might be explained by the racial differences in facial characteristics. A recent anthropometric analysis reported by Kunjur, Sabesan, and Ilankovan (2006) finds that Chinese men and women have wider intercanthal distances than Indian and white men and women. As explained by the authors, the intercanthal distance refers to the most medial part of the palpebral, i.e., the closest distance between the two eyes). In other words, the separation of the eyes is greater in Asian than in Caucasian faces. This racial difference in eye separation also occurs in the faces used in current research, the average eye separation being wider in Asian faces (140.75 pixels, or about 4.1 cm on a 17inches monitor) than in Caucasian faces (135.06 pixels, about 3.95 cm on 17inches monitor). Although the ratio was controlled, the wider eye separation in Asian faces makes the actual movement of the eyes larger, especially when the ratio was considerable. This might explain why the configural discrepancy was easier to detect in Asian faces when the ratio of configural alteration was 20% and 24%.

In sum, the finding that the FIE emerges only under critical configural discrepancy is important and enlightening for research associated with face recognition. In the domain of face recognition, the inversion effect is widely and frequently adopted as an index to examine the underlying mechanism of face processing. The inversion effect is always regarded as an important indicator to justify or disprove different arguments. However, as revealed in the current research, the emergence of the inversion effect might not only depend on the stimuli, task, participant age, etc; it might also be a consequence of a specific ratio of configural alteration. The results apparently cast doubt on the reliability of FIE for being adopted as a prevalent index. Accordingly, the arguments derived from the emergence of FIE should be interpreted carefully, especially when only one ratio of the configural alteration was applied throughout the research. Recently, Russell, Duchaine, and Nakayama (2009) find that the magnitude of FIE is also mediated by the face recognition ability of individuals. People with exceptionally good face recognition ability not only perform better than the normal participants, but also showed a larger FIE than the normal participants. Therefore, it is necessary to deeply scrutinize the fluctuation of FIE in different conditions. Future works might need to examine the susceptibility of FIE to other methodological factors in addition to the factor of ratio of configural alteration. For example, if FIE is also susceptible to the experimental task (recognition, memory, or force choices), the face stimuli (full color, gray scale, or line drawing images), or the participants (gender, motivation, i.e. reward or expertise). The clarification of these questions will be fundamental for researchers in the domain of face recognition to reexamine the role of FIE.

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# 5 1D distortion in Face Recognition: Iris Illusion: External Contour Causes Length-Assimilation Illusions

## 5.1 Abstract

The Delboeuf illusion and the Ebbinghaus illusion (also known as the Titchener illusion) demonstrate that an external contour can lead to size-assimilation and size-contrast perception. This paper explores a novel illusion, revealing that neighboring external contours can also lead to a distortion in length perception. The illusion was originally discovered from a face stimulus (Experiment 1) in which a face was depicted alongside its mirror image so as to make the four irises absolutely equidistant. The distance between the middle two irises was underestimated in Asian faces, but overestimated in Caucasian faces. The illusion was also maintained when the facial stimuli were replaced by line drawings of eyes (Experiment 2). However, the illusion vanished when the irises were presented alone. Further scrutiny of the differences in facial characteristics between Asian and Caucasian faces reveals that the illusion might be elicited by the relative position of the eye shapes. This hypothesis was confirmed in Experiment 3, in which the distances between the eye shapes and the irises were manipulated.

## 5.2 Introduction

Vision is an important faculty which allows human beings to perceive, interpret, and interact with the external world. People are inclined to trust the information conveyed by vision, even though subjectively perceived reality does not always reflect objective physical reality. Hundreds of interesting illusions have been discovered, demonstrating that visual perception may be distorted by the arrangement or presentation of visual stimuli. Among these many illusions, the best-known associated with length and size distortions are probably the Müller-Lyer (Müller-Lyer, 1889) and the Delboeuf illusions (Delboeuf, 1865; 1892; Nicolas, 1995; Oyama, & Goto, 2007; for a review see Goto et al, 2007).

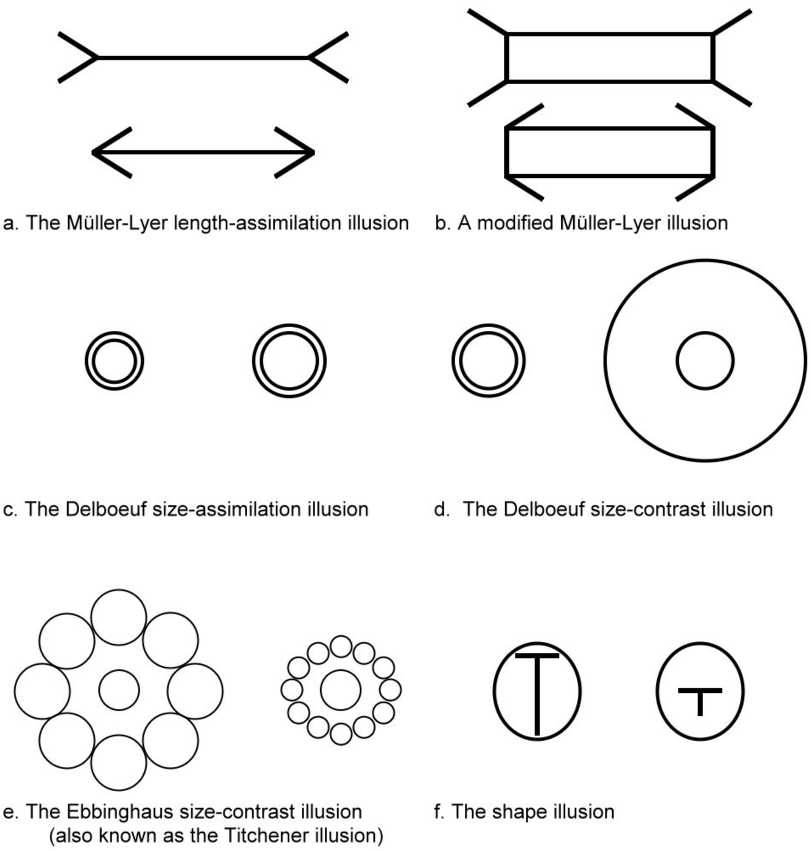



Figure 18. Illustrations of (a). the Müller-Lyer illusion, (b) the modified version of Müller-Lyer illusion, (c) the Delboeuf illusion, (d) the Ebbinghaus illusion, (e) the hollow-face illusion, and (f) the Thatcher illusion.

As shown in Figure 18a, the line with outward-pointing arrowheads at the ends (upper) is strongly perceived as longer than the one with inward-pointing arrowheads at the ends (bottom), despite the two lines being absolutely equal in length. The Müller-Lyer illusion has been widely replicated in various modified versions. However, an interesting contrast to it has been found, revealing that the distortion of width does not conform to that of length (Dengler, 1972; Grigg, 1974; Waite & Massaro, 1970). As shown in Figure 18b, in which the lines between the arrowheads are replaced by rectangles, the rectangle connected to the outward-pointing arrowheads at the ends (upper) is perceived as longer, but also narrower than that connected to the inward-pointing arrowheads at the ends (bottom). In other words, the perceptions of length and of width are distorted in different directions: the length dimension is perceptually enlarged, whereas the width dimension is pertually shrunk.

In the Delboeuf illusion, however, the distortion of the visual experience occurs in the evaluation of stimulus size. A size-assimilation illusion was illustrated in Figure 18c, the concentric outer circle on the left side is perceived as smaller than the concentric inner circle on the right side, even though the two circles are actually equal in size. The perceived size of the circle assimilates toward the size of the neighboring circle. However, an interesting contrary effect of the illusion was demonstrated when the enlargement of the external circle exceeds certain extent (about 5-6 times larger than the internal circles). At the moment, the Delboeuf illusion gradually switches from size-assimilation illusion to size-contrast illusion. As shown in Figure 18d, the concentric inner circle on the left side is now perceived as larger than the concentric inner circle on the right side. This phenomenon indicates that the Delboeuf illusion represents a dynamic integration between assimilation and contrast (for a detail review see Oyama, Torii, & Mochizuki, 2005 and Goto et al, 2007). The Ebbinghaus illusion (Ebbinghaus, 1893; 1902; see Wundt, 1898), also known as the Titchener Illusion (Titchener, 1901), however, demonstrates a different kind of size distortion: mainly a size-contrast illusion. As shown in Figure 18e, the inner circle on the left side is perceived as smaller than the inner circle on the right side, despite the two circles being equal in size.

The neighboring objects elicit not only length and size distortion, but also shape distortion. Lee and Freire (1999) found that changing the arrangement of the facial features within a face can elicit a shape distortion of the external face contour. The illusion remains existent when the face configuration is replaced by a 'T' word. As illustrated in Figure 18f, the left oval is perceived as elongated, taller, and narrower than the right oval despite the two ovals are entirely identical. The Müller-Lyer illusion, Delboeuf illusion, Ebbinghaus illusion, and the shape illusion collectively suggest that human beings perceive the external stimuli in a relative rather than an absolute manner. A length-assimilation, size-contrast, size-assimilation, or shape-distortion effects can be easily elicited by external items. Moreover, different kind of distortion mechanisms are mutual interactive. Apparently, the perception of stimulus dimension is liable to be distorted by external contours.

In this research, I explore a novel illusion which demonstrates that an external contour similar to the outer circle in the Delboeuf illusion can not only lead to a size-contrast, size-assimilation, or shape-distortion effect, but may also result in a distance-assimilation effect as revealed in the Müller-Lyer illusion. Similar to the findings of the shape illusion (Lee & Freire, 1999) that although this novel illusion was originally derived from a complex stimulus (face), it can be replicated by using simple geometric figures. Three experiments were constructed to explore the novel illusion, denominated as Iris Illusion.

## 5.3 Experiment 7

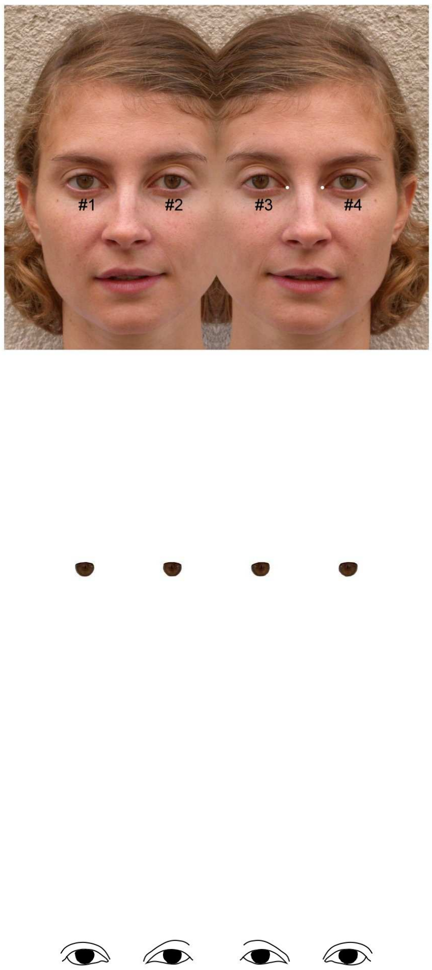
### 5.3.1 Method

#### 5.3.1.1 Participants

Nineteen Swiss undergraduate students (two male and 17 female; mean age 21.6 years) from the University of Zurich participated as one means of fulfilling a psychology course requirement. Sixteen Taiwanese staff (4 male and 12 female; mean age 35.7 years) from HsaunCheing Elementary school in Taipei county, Taiwan participated and received a small monetary reward for their participation.

#### 5.3.1.2 Materials

Sixty-four full-color photographs of faces balanced in race and gender (16 Swiss females, 16 Swiss males, 16 Taiwanese females, and 16 Taiwanese males) were picked at random from a face database assembled by VICOREG (Visual Cognition Research Group at the University of Zürich, Switzerland). Two kinds of stimuli, referred to as face stimuli and iris stimuli, were generated from the 64 selected faces. The face stimuli involved mirror-images of the original faces that were presented alongside the original faces. The resulting four eyes from left to right were denoted as #1, #2, #3, and #4 separately as illustrated in Figure 19a. Eyes #1 and #2 belong to the left-hand face, and eyes #3 and #4 belong to the right-hand face. The distance between Irises #1 and #2 is equal to the distance between Irises #3 and #4 since the faces were mirrored images of each other. Meanwhile, the two faces were carefully merged so as to make the distance between Irises #2 and #3 equal to the distance between Irises #1 and #2 and between Irises #3 and #4. In other words, the four irises are exactly equidistant (see Figures 19a and 20a). The manipulation was applied to the 64 faces. The iris stimuli involved the same procedure, except that all facial content but the irises were deleted (see Figures 19b and 20b). The stimuli were standardized to 1024×768 pixels at 300 dpi resolution.

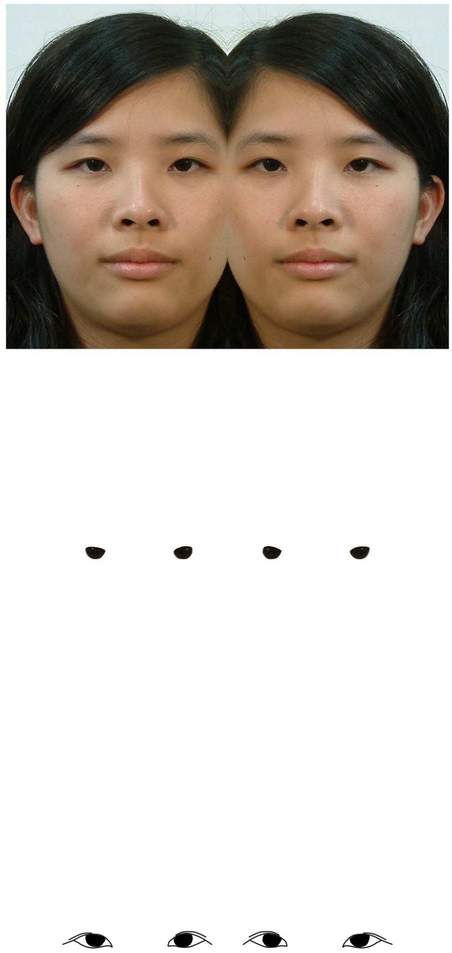



a

b

c

Figure 19. a: One of the Swiss composite faces. The distances between any neighboring two irises are the same (Experiment 1 and 2). b: The counterpart iris image of figure 19a (Experiment 1).
c: The counterpart line-drawing image of figure 19a (Experiment 2). ). The distance between the two red dots is the intercanthal distance, see discussion section.



a

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Figure 20. a: One of the Taiwanese composite faces. The distances between any neighboring two irises are the same (Experiment 1 and 2).
b: The counterpart iris image of figure 20a (Experiment 1).
c: The counterpart line-drawing image of figure 20a (Experiment 2). ). The distance between the two red dots is the intercanthal distance, see discussion section.

5.3.1.3 Procedure

The experiment was a five-factor mixed design with stimulus type (face or iris), face race (Caucasian/Swiss or Asian/Taiwanese), face gender (male or female), and orientation (upright or inverted) as within-subject factors, and participants (Caucasian/Swiss or Asian/Taiwanese) as between-subject factors.

Each stimulus (face stimuli and iris stimuli) was presented on a 17” CRT monitor, once with upright and once with inverted orientation, resulting in 256 trials. The *face/iris stimuli* were presented on the screen without time limit. The viewing distance was about 50 cm. A forced choice paradigm was adopted. Participants were instructed that the distance between irises #1 and #2 was equal to the distance between irises #3 and #4 because the two faces were mirror-images of each other. However, the distance between irises #2 and #3 varied in the stimuli; it could be shorter, longer, or equal to the distance between irises #1 and #2 or between irises #3 and #4. Participants were required to judge whether the distance between irises #2 and #3 was longer, shorter, or equal to the distance between irises #1 and #2 or between irises #3 and #4, and pressed one of the corresponding keys, labeled as ‘Shorter’, ‘Equal’, and ‘Longer’. After their response, a black screen appeared with white text instructing participants to press any key to initiate the next trial. The responses in terms of ‘shorter’, ‘equal’, and ‘longer’ were recorded for further analysis. Eight practice trials balanced in stimulus type, orientation, race, and gender were provided prior to the formal trials for participants to familiarize themselves with the experimental procedure.

5.3.2 Results

5.3.2.1 Percentage

The average probability of the three different perceptions was calculated for each participant in each condition. The data were subjected to five-factor ANOVAs with stimulus type, face race, face gender, and orientation as within-subject factors and participant race as a between-subject factor. Separate ANOVAs were carried out for the judgments of shorter, equal, and longer because these three assessments are dependent on each other.

5.3.2.1.1 Judgment of shorter

Figure 21 illustrates the mean probability and standard errors for the judgment of shorter divided among the factors of stimulus type, face race, and face gender. The judgment of shorter is an incorrect assessment, because the distances are in fact equal. The judgment of shorter implies that the perception of the distance was underestimated. Repeated measure ANOVA on average probability was conducted to examine the frequency of the visual distortion. The ANOVA on average probability for short judgment revealed main effects of stimulus type, $F(1, 33) = 67.536$, $MSE = 14.658$, $p < .001$; face race, $F(1, 33) = 224.322$, $MSE = 5.591$, $p < .001$; and face gender, ($F(1, 33) = 9.812$, $MSE = .131$, $p < .004$. The ANOVA also revealed a significant interaction between stimulus type and face race, $F(1, 33) = 105.741$, $MSE = 4.701$, $p < .001$, and between stimulus type and face gender, $F(1, 33) = 31.611$, $MSE = .419$, $p < .001$. Simple main effect analysis revealed that the difference of the probability for short judgment between Caucasian face and

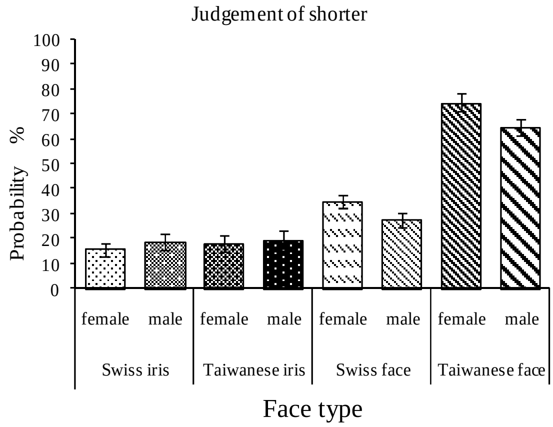


Figure 21. The mean probability and standard errors for the judgment of shorter.

Asian face was significant for face stimulus (*p* < .001) but not for iris stimulus (*p* = .209), and the difference of the probability between female face and male face was also significant for face stimulus (*p* < .001) but not for iris stimulus ( *p* = .109 ).

As can be seen from Figure 21, even though the four irises were in fact always equidistant, participants consistently assess the distance between irises #2 and #3 as shorter in face stimulus, but not in iris stimulus. The results confirm the existence of the new optical illusion, Iris Illusion. The perception of the distance between irises #2 and #3 is perceptually distorted. However, the extent of the length distortion is different between the faces of different races. The illusion is more vigorous in Asian faces than in Caucasian faces. In addition, the illusion is stronger in female faces than in male faces. However, the illusion is demonstrated comparably across participants from different ethnic groups, since the participant factor revealed neither a main effect nor interactions with other factors.

5.3.2.1.2 <u>Judgment of equal</u>

Figure 22 illustrates the mean probability and standard errors for the judgment of equal divided among the factors of stimulus type, face race, and face gender. The judgment of equal is a correct assessment because the distance between irises #2 and #3 is indeed equal to the distance between irises #1 and #2 or between irises #3 and #4. Repeated measure ANOVA on average probability was conducted to examine the frequency of the correct assessment. The ANOVA on average probabili-

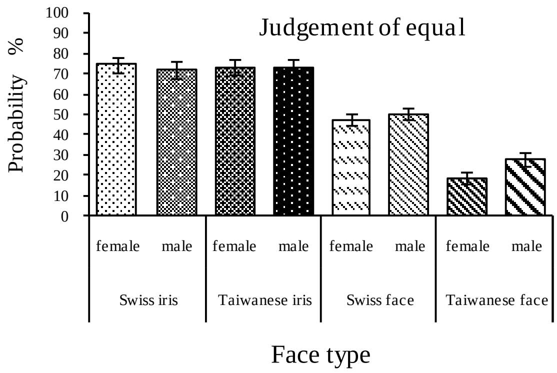


Figure 22. The mean probability and standard errors for the judgment of equal.

ty for equal judgment revealed main effects of stimulus type, $F(1,33) = 99.237$, $MSE = 19.153$, $p < .001$, and face race, $F(1, 33) = 113.590$, $MSE = 2.275$, $p < .001$. The ANOVA also revealed significant interaction between stimulus type and face race, $F(1, 33) = 66.463$, $MSE = 2.249$, $p < .001$, and between stimulus type and face gender, $F(1, 33) = 10.094$, $MSE = .182$, $p < .003$. Simple main effect analysis revealed that the difference of the probability between Caucasian face and Asian face and between female face and male face were significant for face stimulus ($p$s $< .001$) but not for iris stimulus ($F$'s $< 1$). There was no main effect of participant group (Swiss vs. Taiwanese) and no interaction between participant group and other factors.

As can be seen from Figure 22, participants correctly assessed the distance between the irises # 2 and #3 as equal in iris stimulus but not in face stimulus. The results are in accordance with the effect of the illusion, indicating that the assessment of the distance remained intact in iris stimulus. The presentation of isolated irises did not lead to a distortion in length perception.

5.3.2.1.3 Judgment of longer

Figure 23 illustrates the mean probability and standard errors for the judgment of longer divided among the factors of stimulus type, face race, and orientation. The judgment of longer is also an incorrect assessment, because the distances are in fact equal. The judgment of longer implies that the perception of the distance was overestimated. Repeated measure

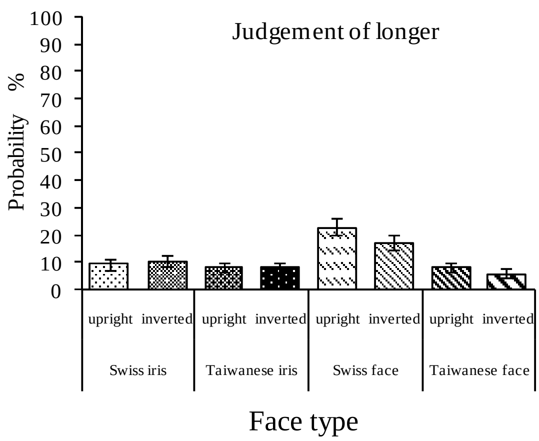


Figure 23. The mean probability and standard errors for the judgment of longer.

ANOVA on average probability was conducted to examine the frequency of the visual distortion. The ANOVA on average probability for longer judgment revealed a main effect of face race, $F(1, 33) = 36.576$, $MSE = .743$, $p < .001$, and significant interactions between stimulus type and face race, $F(1, 33) = 18.623$, $MSE = .447$, $p < .001$, and between stimulus type and orientation, $F(1, 33) = 8.689$, $MSE = .068$, $p < .006$. Simple main effect analysis revealed that difference of the probability between Caucasian face and Asian face was significant for face stimulus ( $p < .001$) but not for iris stimulus ( $p = .076$ ); and the difference of the probability between upright face and inverted face was significant for face stimulus ( $p < .008$ ) but not for iris stimulus ($F < 1$ ).

As can be observed from Figure 23, an opposite effect of Iris Illusion was found when participants were required to assess the distance in Caucasian faces. Participants tended to assess the distance as longer in Caucasian faces. The opposite effect of the illusion was demonstrated to the same extent on participants from the two different ethnic groups. However, the opposite effect of the illusion did not occur when participants were required to assess the distance in Asian faces. Further scrutiny of the data revealed that the opposite effect of the illusion occurs consistently on some specific Caucasian faces.

### 5.3.3 Discussion

Overall, the results of Experiment 7 broadly confirm the emergence of the new illusion. Positioning an image of a face alongside its mirrored image can elicit a distortion in length perception. Participants consistently assessed the distance between irises #2 and #3 as shorter than the distances between irises #1 and #2 or between irises #3 and #4. The illusion emerged only when the irises were imbedded in the facial context, not when the irises were presented alone. The magnitude of the illusion seems to be more vigorous in Asian faces than in Caucasian faces. Interestingly, an opposite effect of the illusion was observed on some Caucasian faces, revealing that the distance was assessed as longer instead of shorter in these Caucasian faces. The illusion was independent of the orientation of the face stimulus and the races of participants.

## 5.4 Experiment 8

Although the new illusion demonstrated in Experiment 7 was observed originally from face stimulus, the illusion seems to be dissociated from the influence of face perception, which is vulnerable to cross-race recognition and inversion. Instead, the illusion seems to be related to the geometrical attributes of the regions around the eyes. Experiment 8 aims to explore whether the illusion is elicited merely by the shape of eyes.

### 5.4.1 Method

#### 5.4.1.1 Participants

Fifteen undergraduate Swiss students (14 Female; mean age 22.7 years) from the University of Zurich participated in the experiment as means for fulfilling the psychological course requirement. Sixteen Taiwanese staff (13 Female; mean age 37.2 years) from HsaunCheing Elementary school in Taipei county, Taiwan participated in the experiment and received a small monetary reward for participation.

#### 5.4.1.2 Materials

Two kinds of stimulus were used in Experiment 8. The iris stimulus was identical to that used in Experiment 7, as displayed in figure 19b and 20b. However, the face stimuli were replaced by another set of stimuli termed as line drawing eye stimuli. The line drawing stimuli were generated from the face stimulus used in Experiment 7. The contours (shapes) of the eyes of each face stimulus were depicted via PhotoImpact 10 and the irises remained inside the eye shapes as illustrated in figure 19c and 20c.

5.4.1.3 <u>Procedure</u>

The design and procedure of Experiment 8 were identical to those of Experiment 7.

5.4.2 <u>Results</u>

5.4.2.1 <u>Percentage</u>

The method of analysis in Experiment 8 is identical to that used in Experiment 7

5.4.2.1.1 <u>Judgment of shorter</u>

Figure 24 illustrates the mean probability and standard errors for the judgment of shorter divided among the factors of stimulus type, face race. As in experiment 7, the judgment of shorter implies that participants tended to underestimate the distance. Repeated measure ANOVA on average probability was conducted to examine the frequency of the visual distortion. The ANOVA on aver-

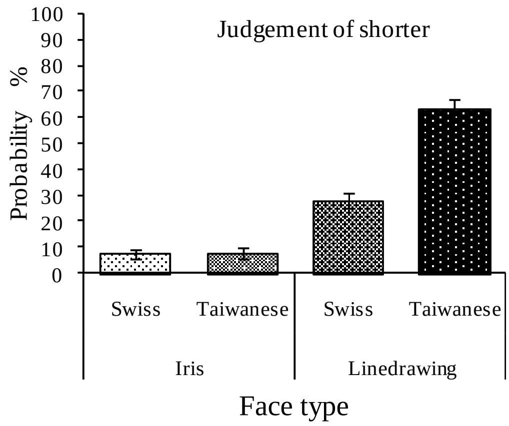


Figure 24. The mean probability and standard errors for the judgment of shorter.

age probability for shorter judgment revealed main effects of stimulus type, $F(1,29) = 194.231$, $MSE = 17.914$, $p < .001$; and face race, $F(1, 29) = 182.197$, $MSE = 4.019$, $p < .001$. The ANOVA also revealed a significant interaction between stimulus type and face race, $F(1, 29) = 223.853$, $MSE = 3.758$, $p < .001$. Simple main effect analysis revealed that the difference of the probability between Caucasian face and Asian face was significant for line drawing stimulus ($p < .001$) but not for iris stimulus ($F < 1$). As can be seen from Figure 24, Experiment 8 revealed the similar pattern as in Experiment 7. Participants judged the distance between irises #2 and #3 as shorter than that between irises #1 and #2 or between irises #3 and #4 when assessing line drawing stimulus but not when assessing iris stimulus. The illusion was stronger when participants assessed Asian faces than when they assessed Caucasian faces. However, in contrast to Experiment 7, the effect of face gender vanished in line drawing stimulus. The results of Experiment 8 indicated that the length distortion can also be elicited by merely presenting the line drawing of the eye shapes.

5.4.2.1.2 Judgment of equal

Figure 25 illustrates the mean probability and standard errors for the judgment of equal divided among the factors of stimulus type, face race. As in Experiment 7, the judgment of equal is the only correct response. Repeated measure ANOVA on average probability was conducted to examine the frequency of the visual acuity. The ANOVA on average probability for equal judgment revealed

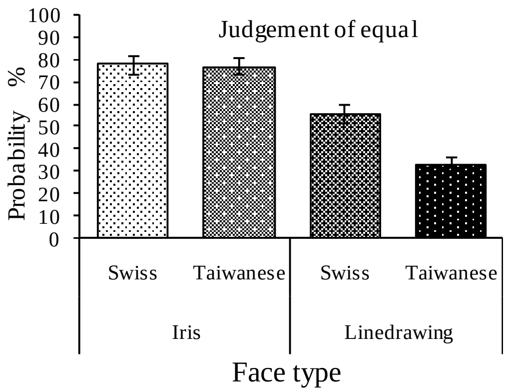


Figure 25. The mean probability and standard errors for the judgment of equal.

main effects of stimulus type, $F(1,29) = 105.039$, $MSE = 13.747$, $p < .001$, and face race, $F(1, 29) = 56.824$, $MSE = 1.736$, $p < .001$. The ANOVA also revealed a nificant interaction between stimulus type and face race, $F(1, 29) = 56.294$, $MSE = 1.536$, $p < .001$. Simple main effect analysis revealed that the difference of the probability between Caucasian face and Asian face was significant for line drawing stimulus ($p < .001$) but not for iris stimulus ($F < 1$). Identical to the results of Experiment 7, participants correctly assessed the distance between irises #2 and #3 as equal when only the irises were presented. The probability of correct assessment reduced when the irises were presented with line drawing of eye shapes. The reduction of correct assessment of the distance in line drawing stimuli conforms to the existence of the illusion.

5.4.2.1.3 Judgment of longer

Figure 26 illustrates the mean probability and standard errors for the judgment of equal divided among the factors of stimulus type, face race. As in Experiment 7, the judgment of longer implies an overestimation of the length perception. Repeated measure ANOVA on average probability was conducted to examine the frequency of the distortion. The ANOVA on average probability revealed main effects of face race, $F(1, 29) = 33.937$, $MSE = .472$, $p < .001$ and a significant interaction between stimulus type and face race, $F(1, 29) = 35.716$, $MSE = .489$, $p < .001$. Simple main effect analysis revealed that the differ-

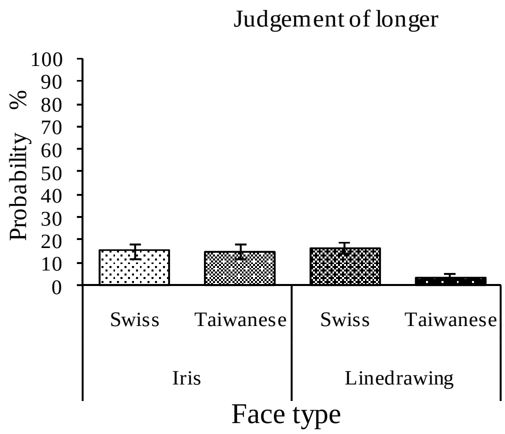


Figure 26. The mean probability and standard errors for the judgment of longer.

ence of the probability between Caucasian face and Asian face was significant for line drawing eye stimulus ($p < .001$) but not for iris stimulus ($F < 1$).

As can be seen from Figure 26, overall, the assessment of longer is relatively infrequent. However, the distance between irises #2 and #3 was judged as longer more often in Caucasian line drawing stimulus than in Asian line drawing stimulus. Similar to the results of Experiment 7, participants from the two different ethnic groups also demonstrated an opposite effect of the illusion when assessing the distance in a Caucasian line-drawing stimulus.

### 5.4.3 Discussion

Overall, the results of Experiment 8replicated the results of Experiment 7, revealing that depiction of mere line drawings of the facial eyes can also elicit the illusion to the same extent as full face stimulus. The pattern of the illusion in Experiment 8 was almost identical to Experiment 7, except that the gender effect and its interaction with other factors disappeared in the judgment of shorter in Experiment 8.

Although in Experiment 7, female face stimuli seem to elicit stronger illusion than male face stimuli, the influence from the gender of the face stimuli was weak. The influence from face gender vanishes when line drawings stimulus were adopted in Experiment 8. Consequently, the emergence of gender effect must be due to gender related properties of the photographic images such as the shape of nose, mouth and other features, texture, or make-up.

On the contrary, the shape of the eyes and the distance between the eyes might be the critical contributor associated with the new illusion. Moreover, the opposite effect demonstrated in Asian vs. Caucasian faces could be due to the racial difference in the eye regions of the faces. A recent anthropometric analysis reported by Kunjur, Sabesan, and Ilankovan (2006) found that Chinese men and women had wider intercanthal distances than Indian and white men and women. As explained by Kunjur et al (2006), the intercanthal distance referred to the most medial part of the palpebral, illustrated in Figure 19 as the distance between the two small red dots. To examine this facial geometrical difference between Asian and Caucasian faces, Imeasured the intercanthal distances and the widest part of the face for all the 64 faces used in this research, and calculated the relative proportion (intercanthal distances/face width). The proportion in Asian faces (M = .256) is significant higher than that in Caucasian faces (M = .23), $t(62) = 5.110$, $p < .001$. This anthropometric analysis not only confirms the findings of Kunjur et al (2006) but also provides an important cue for exploring the origin of the new illusion.

To manifest the difference between the line drawings of eye shapes that elicit the opposite effect of the illusion, I morphed the top three line drawings images which elicited the strongest illusion in divergent effects (longer vs. shorter). Only the top three faces which elicit the strongest illusion were included for the morphing because the illusion was elicited to different extent depending on the face stimuli used in the experiment. Some faces consistently elicit the same illusion by different viewers, but some faces demonstrate variable effect by different viewers. Selecting only the top three faces which elicit the strongest illusion would be easier to detect the facial characteristics which elicit the illusion. The three line drawings images which induced the strongest ’longer’ illusion (enlarged effect) were morphed by FantaMorph software, so as the three line drawings images which induced the strongest ’shorter’ illusion (shrinking effect) . Figure 27 illustrates the results of the morphing for the two opposite effect. The original sizes of the eyes were adjusted to equalize the distances between the irises of the two outputs for parison. As can be seen in Figure 27A, the eye shapes #1 and #2 and eye shapes #3 and #4 seem to be close to each other in the image which elicits the longer illusion. As a result, eye shapes #2 and #3 seem to be apart in Figure 27A. By contrast, in Figure 27B, the eye shapes #1 and #2 and eye shapes #3 and #4 seem to be apart from each other in the image which elicits the shorter illusion. As a result, eye shapes #2 and #3 seem to be close in Figure 27B. Accordingly, the difference of the facial characteristic might be a critical factor for the emergence of the illusion. In light of these findings, I designed Experiment 9 to examine whether the illusion was elicited by the relative position of eye shapes and irises.

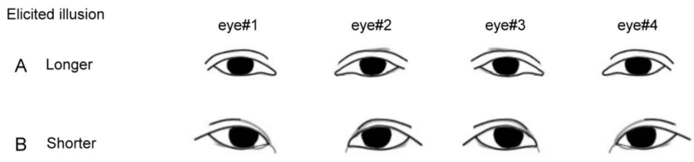


Figure 27. The outputs of the morphing of the line drawings of eyes shape. The input of the morphing contains the top three line drawings of eyes shape which elicit the strongest effect in different directions.

## 5.5 Experiment 9

The results of Experiment 7 and 8, and the finding of the face morphing, imply that the opposite illusion demonstrated in Experiments 7and 8 might be elicited by the intercanthal distances of the faces and the relative position of the eye shapes and the irises inside the eyes. Figure 28 provides an extreme example of the Iris Illusion. In 'none eye shapes', the distance between iris #2 and #3 are per-

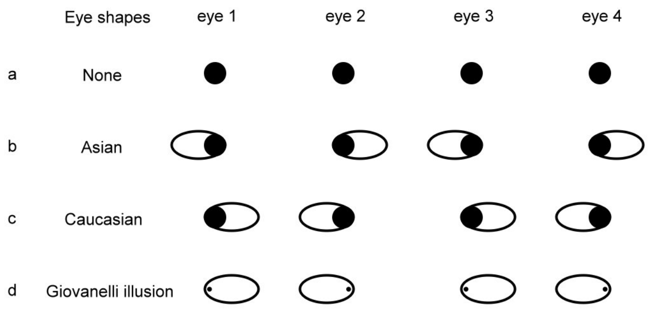


Figure 28. An extreme caricature illustration of the Iris Illusion.

ceived as equal to the distance between irises #1 and #2, and between irises #3 and #4. This pattern was confirmed in Experiment 7 and 8 that no illusion occurs when only the irises were presented in the stimulus. In ‘Asian eye shape’, the distance between irises # 2 and #3 are perceived as shorter than the distance between irises # 1 and #2 or between irises #3 and #4, which in again confirmed in Experiment 7 and 8 when Asian faces were judged. Meanwhile, in ‘Caucasian eye shapes’, the distance between irises #2 and #3 are perceived as longer than the distance between irises #1 and #2, or between irises #3 and #4, which is also found in Experiments 7 and 8 when some Caucasian faces were judged.

Experiment 9 aims to examine this hypothesis by manipulating the intercanthal distances of the faces and the relative position of the eye shapes and irises. I created four irises and four eye shapes, and manipulated the inward or outward movement of the eye shapes. I predict that if the opposite effect of the illusion is elicited by the relative position of the eye shapes and the irises, the distance between irises #2 and #3 should be overestimated when the paired eye shapes (eye shape #1 vs. eye shape#2, and eye shape #3 vs. eye shape #4) are moved inwards, similar to the Caucasian eye shapes in Figure 28. By contrast, the distance between irises #2 and #3 should be underestimated when the paired eye shapes are moved outwards, similar to the Asian eye shapes in Figure 28. In order to prevent the possible disturbance caused by the same correct answer throughout the whole experiment, the distance between the irises were also manipulated. Participants would sometimes have to respond ‘longer’ and sometimes ‘shorter’. Such a procedure helps to keep the participants engaged in the task and remain motivated.

### 5.5.1 Method

5.5.1.1 Participants

Only Caucasian participants were recruited to participate in Experiment 9 since the illusion was demonstrated equally among participants from different ethnic groups, as found in Experiment 7 and 8. Eighteen students (11 Female; mean age 24.45 years) from the University of Zurich participated in the experiment. Participants received either a credit point required for a psychology course or small monetary reward for their participation.

5.5.1.2 Materials

Two factors were manipulated in the experiment: iris distance and eye shape movement, as shown in the columns and rows in Figure 29.

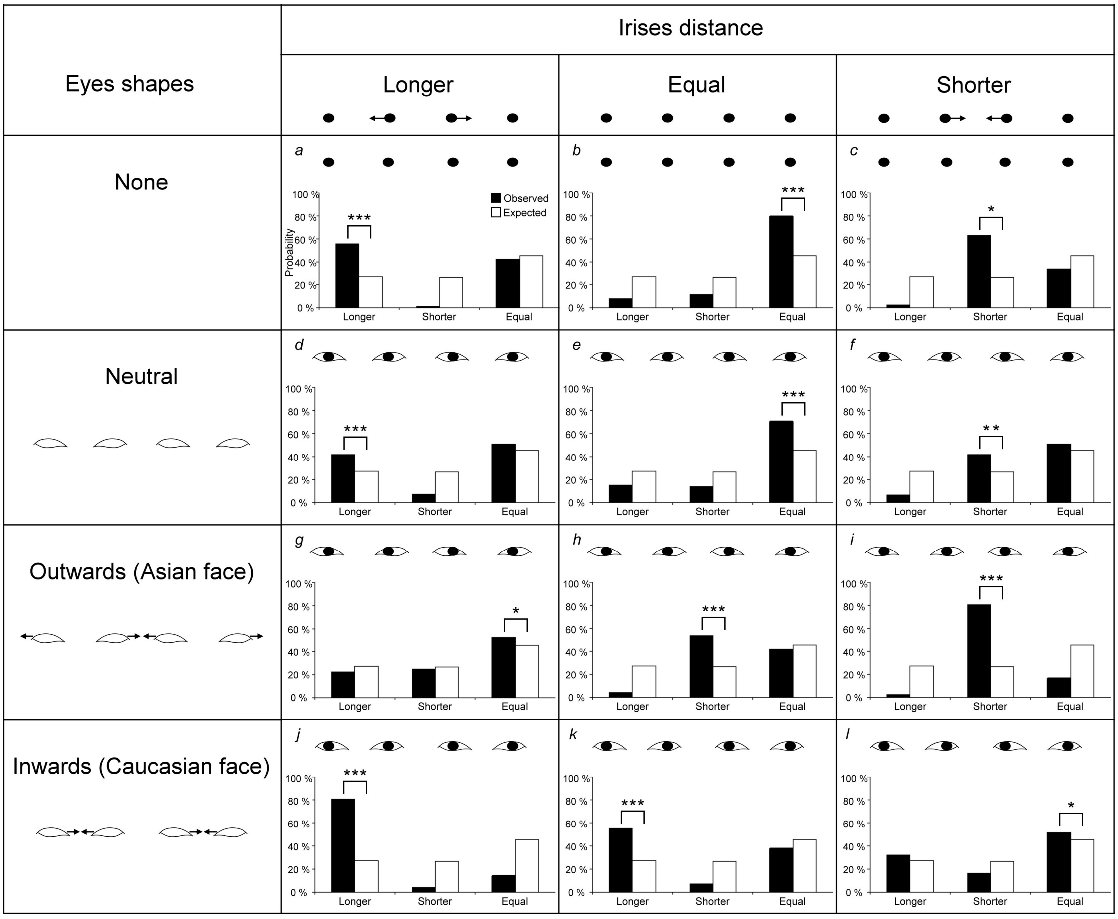


Figure 29. Demonstrations of the stimuli and results of Experiment 9.

Twelve stimuli were created by the combination of these two factors. The factor of iris distance contained three levels: equal, longer, and shorter. In the equal condition, four irises were created and the distances between any neighboring two irises were equal, as illustrated in the Equal column in Figure 29.

In the longer condition, the distance between irises #2 and #3 was moved apart for 10 pixels (one eye for 5 pixels) as illustrated in the Longer column in Figure 29. The separation of 10 pixels was about 0.3 cm on the 17” monitor, subtending about 0.34 degree from a viewing distance of 50 cm. In shorter condition, the distance between irises #2 and #3 were moved closer for 10 pixels (one eye for 5 pixels) as illustrated in the Shorter column in Figure 29.

The factor of eye shape movement contained four levels: None, Neutral, Outwards, and Inwards as illustrated in the left most panel in Figure 29. There were no eye shapes in the ’None‘ eye shapes condition. In the ‘Neutral’ eye shapes condition, two pairs of line-drawing eye shapes were created such that the four irises in equal condition will locate in the middle of the eye shape, as shown in Figure 29*e*. In the ‘Outward’ eye shapes condition, the eye shapes #1 and #3 were moved leftwards for 8 pixels, and the eye shapes #2 and #4 were moved rightwards for 8 pixels. The additional separation of 16 pixels between eye shapes #1 and #2 and between eye shapes #3 and #4 were was about 0.5 cm on the 17” monitor, subtending about 0.57 degree from a viewing distance of 50 cm. This condition was created to mimic the facial characteristics of Asian faces. In the ‘Inward’ eye shapes condition, the eye shapes #1 and #3 were moved rightwards for 8 pixels, and eye shapes #2 and #4 were moved leftwards for 8 pixels. This condition was created to mimic the facial characteristics of Caucasian faces. The movement of the eye shapes was exactly in opposite direction between the ‘Outward’ and ‘Inward’ eye shapes conditions.

The three levels in the factor of irises distance were applied to the four manipulations in the factor of eye shape movement. As a result, twelve combinations between manipulations of irises distance and eyes shape movement were generated as illustrated from Figures 29*a* to 12*l*.

#### 5.5.1.3 Procedure

The 12 conditions were repeated 18 times, resulting in 216 trials. The 216 trials were presented randomly on a 17” CRT monitor without time limit. The viewing distance is about 50 cm. Participants were informed that the distance between irises #1 and #2 was equal to the distance between irises #3 and #4. However, the distance between irises #2 and #3 was either increased, decreased, or remained unchanged. They were instructed to judge whether the distance between iris #2 and #3 was shorter, equal, or longer compared to the distance between iris #1 and #2 or between iris #3 and #4. Participants were required to press one of the three corresponding keys labeled as ‘Longer’, ‘Shorter’ and ‘Equal’ for their assessment. After participants responded, a mask (colorful random dot image) was shown on the screen for 1000 milliseconds and the next trial appeared immediately after the end of the mask stimulus. Twelve practice trials containing each condition were provided prior to the formal experiment for the participants to familiarize themselves with the procedure. The responses in the practice trials were not included in the analysis.

### 5.5.2 Results

The overall probabilities for the longer, shorter, and equal responses were 27 %, 27 %, and 46 % respectively. The probability was not equivalent among the three possible choices, even though the whole trials were distributed equivalently between the three choices. Participants revealed a higher tendency to assess the distance as equal rather than longer or shorter. The conservative response strategy might be due to the subtle discrepancy between the distances. Therefore, the chance level of the selections among the three choices (shorter, equal, and longer) should be adjusted to take into account the biased response strategy. The overall probability for the three choices which could appropriately reflect participants' response strategy served as a better baseline and was therefore set as chance level for further comparison. The difference between the chance level and the observed probability in different condition was examined by Two Sample Proportion z-Test.

The results are shown in Figure 29. The asterisks denote the conditions in which the observed probability is significantly higher than the chance level, indicating a bias towards the length perception. The relative statistics of the conditions where the observed probability is significantly higher than the chance level is also shown in Table 1. The major findings are reported as follows in order of the manipulation in the factor of irises distance.

Table 1. The statistics of the conditions where the observed probability is significantly higher than the chance level.

| Dot distance | Eye shapes manipulation | Participants' perception | Figure | Probability difference [1] | Z-score | *P* value |
|---|---|---|---|---|---|---|
| Equal | None | Equal | b | .34 | 14.59 | < .001 |
| | Neutral | Equal | e | .25 | 9.51 | < .001 |
| | Outward | Shorter | h | .27 | 9.27 | < .001 |
| | Inward | Longer | k | .28 | 9.66 | < .001 |
| Longer | None | Longer | a | .28 | 9.94 | < .001 |
| | Neutral | Longer | d | .15 | 5.16 | < .001 |
| | Outward | Equal | g | .07 | 2.54 | =.011 |
| | Inward | Longer | j | .54 | 23.54 | < .001 |
| Shorter | None | Shorter | c | .36 | 12.88 | < .001 |
| | Neutral | Shorter | f | .15 | 5.32 | < .001 |
| | Outward | Shorter | i | .53 | 22.83 | < .001 |
| | Inward | Equal | l | .06 | 2.21 | =.027 |

[1] Probability difference refers to the difference between observed probability and chance level.

#### 5.5.2.1 Equal distance

As shown in the middle column in Figure 29, participants correctly judged the distance between irises #2 and #3 as equal to the distance between irises #1 and #2 or between irises #3 and #4 when the eye shapes were removed, i.e. in None eye shapes condition (Figure 29*b*), or when the irises were positioned in the center of eye shapes, i.e. in Neutral eye shapes condition (Figure 29*e*). However, the perception was distorted in different directions depending on whether the eye shapes were moved outward or inward. Participants tended to underestimate the distance when the eye shapes were moved outward, and frequently misjudged the equal distance as shorter, as illustrated in Figure 29*h*. By contrast, they tended to overestimate the distance and frequently misjudged the equal distance as longer when the eye shapes were moved inward, as illustrated in Figure 29*k*.

#### 5.5.2.2 Longer distance

As shown in the second left column in Figure 29, similar to the equal distance condition, the perception was unbiased when the eye shapes were removed, i.e. in None eye shapes condition (Figure 29*a*), or when the irises were positioned in the center of the eye shapes, i.e. in Neutral eye shapes condition (Figure 29*d*). Participants correctly judged the distance between irises #2 and #3 as longer than the distance between irises #1 and #2, or between irises #3 and #4. However, they tended to underestimate the distance and significantly misjudged the longer distance as equal when the eye shapes were moved outward, as shown in Figure 29*g*. By contrast, they tended to overestimate the distance and enhanced the longer perception when the eye shapes were moved inward as shown in Figure 29*j*.

#### 5.5.2.3 Shorter distance

Repeatedly, the perception was intact in the None-eye shapes (Figure 29*c*) or in Neutral-eye shapes (Figure 29*f*.) conditions. Participants correctly judged the distance as shorter in these two conditions. However, the shorter perception was enhanced when the eye shapes were moved outward, as shown in Figure 29*i*. By contrast, the shorter distance was overestimated and misjudged as equal when the eye shapes were moved inward, as shown in Figure 29*l*.

### 5.5.3 Discussion

The results of Experiment 9 were in accordance with the findings of Experiments 7 and 8, revealing that the external contour can elicit length-assimilation illusion when participants are required to assess the distances between the objects enclosed by the contour. The opposite effects of the illusion demonstrated in Experiments 7 and 8 were successfully replicated by moving the eye shapes inward or outward. These results confirm the hypothesis that the illusion was elicited mainly by the external contour and the position of irises enclosed in the eyes. Moreover, moving the external contour in different directions can generate contrary effects of the illusion. The distances between irises # 2 and #3 were underestimated when the eye shapes were moved outwards. However, the distance between irises # 2 and #3 was overestimated when the eye shapes were moved inwards. Apparently, the perceived iris positions assimilate toward the centers of the eye shape positions and lead to the length distortion.

## 5.6 General Discussion

The Müller-Lyer, Delboeuf, Ebbinghaus, and shape illusions demonstrate that neighboring external contours or inner object can lead to either length-assimilation, size-assimilation, size-contrast, or shape-distortion illusions. This paper explores a novel illusion, Iris Illusion, demonstrating that moving the neighboring external contours can lead to a distance-assimilation. Moreover, the distance-assimilation illusion can be elicited in different manners (overestimation vs. underestimation of the distance) depending on the direction of the movement.

Although discovered originally from face stimulus, the illusion seems not pertain to the mechanism of face processing for two reasons. First, Iris Illusion is independent of orientation which is different from higher level face processing where inversion leads to substantial impairment for face processing (Yin, 1969, for reviews see Valentine 1988, Schwaninger, Carbon, & Leder 2003). The Iris Illusion may involve in the mechanism different from that of the shape illusion found by Lee and Freire (1999). Lee and Freire (1999) found that the effect of the shape illusion is strongly reduced by inversion. The dependence of the shape illusion to the upright orientation suggests that the shape illusion is mainly elicited by the facial configuration as humans are impaired to process the configural information in inverted faces (Searcy & Bartlett, 1996; Freire, Lee, & Symons, 2000; Murray, Yong, & Rhodes, 2000; Schwaninger & Mast, 2005). On the contrary, the independence of orientation in Iris Illusion suggests that Iris Illusion might be elicited mainly by isolated face component rather than the overall facial configuration as facial component processing is much uninfluenced by the orientation (Searcy & Bartlett, 1996; Freire, Lee, & Symons, 2000; Murray, Yong, & Rhodes, 2000; Schwaninger & Mast, 2005). Second, Iris Illusion is demonstrated to the same extent by participants from different ethnic groups. These results are different from face recognition, because several studies have found that humans perform face recognition tasks better for faces from their own race than for faces from other races (e.g. Hayward, Rhodes, & Schwaninger, 2008; for reviews see Meissner & Brigham, 2001).

The most striking and remarkable aspect regarding the illusion is the opposite effect demonstrated in Iris Illusion. However, as for why moving the eye shapes inward or outward in reference to the enclosed irises can induce the opposite effect of inter-irises distance perception may still need to be clarified. Gregory (1963; 1968) proposed a notion of 'misapplied size constancy scaling' to explain the distance-contrast effect demonstrated in the Müller-Lyer illusion (Figure 18A). He argued that the occurrence of the Müller-Lyer illusion was due to the inappropriate registration of depth cues. The shafts inside the arrowheads were unconsciously registered as being of different depths. The size constancy scaling mechanism in our vision automatically takes into account the different depths, and so interpreted the distance differently. This proposition, however, cannot be applied to explain the Iris illusion, because the curvatures of the eye shapes are in identical directions in both Caucasian and Asian faces. Moreover, the illusion occurs in plane, without any involvement of depth registration. Obviously, Gregory's concept cannot appropriately account for the emergence of the illusion.

Giovanelli (Giovenelli, 1966; Giovanelli & Sinico, 2005) ever introduced an illusion which seems to be similar to the Iris Illusion. As illustrated in Figure 28d, Giovanelli found that the dot inside the circle seems to shift in position away from the center of the circle. Giovanelli illusion is fundamentally a position-contrast illusion as the dot tends to deviate to the opposite direction.  However, a very interesting contrary effect is demonstrated between Giovanelli illusion and Iris Illusion.

As shown in Figure 28d, the Giovanelli illusion is replicated 4 times and arranged similarly to the spatial pattern of Iris Illusion. According to the prediction of Giovanelli illusion, the dots #1 and #3 would tend to shift away to the left side, whereas the dots #2 and #4 would tend to shift away to the right side. In this manner, dots #2 and #3 would be perceived to move closer to each other, while dots #1 vs. #2 and dots #3 vs. #4 would be perceived to move apart from each other. Accordingly, it would be reasonable to predict that humans would perceive the distance between dots #2 and #3 (move closer) to be shorter than the distance between dots #1 and #2 or between dots #3 and #4 (move apart). However, contrary to the expectation of Giovanelli illusion, an entirely opposite effect was demonstrated in Iris Illusion. Results of experiments 7 to 9 in current research clearly show that participants tend to perceive the distance between irises #2 and #3 to be longer than the distance between irises #1 and #2 or between irises #3 and #4 as illustrated in Figure 28c. Participants perceive the irises to shift to the congruent direction as the movement of the eye contour instead of to the opposite direction as expected by Giovanelli illusion. Apparently, an effect of position-assimilation occurs and hence it leads to a distortion in distance judgment. The position-contrast assumption as predicted by Giovanelli illusion cannot apply to Iris Illusion.

In the three experiments of this research, participants were required to judge the distance between two dots and compare the virtual distances between any two dots. Apparently, participants might make their distance judgment based on the position of the dots. It is then plausible to consider Iris Illusion as a position-distortion illusion. However, we regard Iris Illusion as a distance-distortion illusion based on the following four reasons. First, although participants were required to judge the distance represented by two end-points without a solid line connecting each other, optical illusions, such as for example the Müller-Lyer illusion are described as a distance distortion illusion even if no connecting line is used between the < > < stimuli (e.g. DeLucia & Hochberg, 1991; Gillam, 1998; Goldstein, 2007). Second, the participants in our experiments were instructed to judge the distance between two dots and not the position of the dots during the tests (participants were not required to evaluate whether the dots shift leftwards or rightwards). Regarding Iris Illusion as a distance-distortion illusion would more realistically reflect the mental perception of the participants' judgment during the test. Third, in real live, when the instruction "estimate the distance between A and B" is used, there is often no connecting line between the two points A and B (e.g. estimate the distance between two football players on a soccer field or the distance between two trees in the wood, etc.). Fourth, Schwaninger, Ryf, and Hofer (2003) applied the method of adjustment and found that participants tend to overestimate the distance between eye and mouth for 39% and the inter-eye distance for 11% although no connecting line was on the faces to be judged. Nevertheless, Iris Illusion is, nevertheless, highly related to a position-distortion illusion. It might be reasonable to say that the distance-distortion is based on the position-distortion. However, it would be confounding to define Iris Illusion as a position-distortion illusion as the position itself was not directly evaluated.

In sum, the results of the experiments show that the external contour which can elicit size-assimilation distortion in Delboeuf illusion can also lead to distance-assimilation distortion. The perceived positions of the inner objects assimilate toward the centers of the external shape positions, something like a Müller-Lyer illusion. The illusion implies that human perception depends on the mechanism which automatically integrates the attended information with the irrelevant neighboring information. Apparently, humans cannot free themselves from the influence of peripheral information when intentionally attending to a central target. This research presents an initial finding of Iris Illusion and more effort should be devoted to clarify the mechanism of the Iris Illusion in order to better understand the perceptual mechanism underlying the illusion. The finding of the illusion is not only interesting for visual perception research but also enlightening in other domains when a visual effect of enlargement or shrinkage in distance is demanded, such as the design of clothing, advertisements, art works, buildings, etc.

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# 6 Spatial Representations in Nature Environment: Turn Right or Turn Left? Heuristic of Adhering to the Direction of Destination

## 6.1 Abstract

It has been found that humans tend to avoid the middle routes and prefer the peripheral routes among multiple choices. Moreover, humans also rely on the 'initial segment strategy' to select the route taken. In this paper, I propose a new heuristic which humans apply during route selection: participants prefer the route whose initial direction lies in the direction of their final destination, while avoiding the route whose initial direction does not. Four maps were designed. The pathways, on different maps, constituted a parallelogram, a rectangle, and a square. Pedestrians were instructed to select a route from an origin to a destination on one of the maps. The results confirm the application of the newly proposed heuristic. In addition, a participant's current viewpoint is also found to mediate route selection. Other possible factors, such as handedness, route angles, and occurrence of turns were excluded. Moreover, the heuristics of deferring decision (Christenfeld, 1995) and relying on initial straightness (Bailenson el al, 2000) are not supported. The possible origin and the importance of the preference are discussed.

## 6.2 Introduction

Intentional locomotion between two locations is an ordinary activity which involves at least three major constituents: positioning (spatial representation), wayfinding (memory & problem solving), and selection (decision-making). Firstly, people must establish a spatial representation of their current position and confirm the position of the desired destination. Secondly, they must identify the potential connective pathways between these two positions. Thirdly, they must select one from all the possible routes. Considerable effort has been devoted to exploring the complex mental processes of the first two elements since the late 1970s (for a review see Arthur & Passini, 1992; Golledge, 1999). In comparison, the process of route selection has been less fully explored.

During the positioning stage, people rely on information derived from the spatial frames of reference (SFR) in the environment to position the current location and the attempted destination (Hart & Moore, 1973; Pailhous, Lepecq, & Pèruch, 1987; Pèruch, Pailhous, & Deutsch, 1986). A substantial quantity of research has demonstrated that the spatial representation based on the external SFR is orientation dependent. The alignment of the external SFR via maps, landmarks, and reference points can facilitate positioning (Marvin, Marchon, & Hanley, 1984; Rossano & Warren, 1989; Iachini & Logie, 2003). After the current location and the desired destination have been confirmed, the next step is to determine the possible pathways which connect the two locations. In the last few decades, a growing body of literature has probed this process, called way-finding (for a review see Arthur & Passini, 1992; Golledge, 1999). External information, such as the complexity of a floor plan, can influence way-finding; performance increases as floor plan complexity decreases. Moreover, the addition of signage can increase the rate of travel by 13% and decrease the rate of wrong turns by 50% (O'Neill, 1991). The visibility of facilities (e.g., a parking deck entrance) can also cause significant differences in reported turning behavior (Carpman, Grant, & Simmons, 1984).

Regarding the process of route selection, it is not surprising that familiarity, distance, time required, and priority might influence our selection of routes when there are alternative options (Seneviratne & Morrall, 1985; for a review, see Golledge, 1999). However, the most interesting finding associated with route selection is the asymmetric pattern when these factors have been controlled. Robinson (1933) observed that there is a strong tendency for museum visitors to bear to the right (75%) when entering a gallery. In contrast, he showed that curators have a persistent tendency to lay out the exhibits in direct opposition to this habitual direction. Scharine and McBeath (2002) also found that right-handers and Americans favor turning to the right when being instructed to search for a note in a T-maze task. The asymmetries of route selection are especially striking when people are required to travel from an origin to a destination; depending on which location is the origin and which is the destination, humans prefer different routes when traveling between two locations (Christenfeld, 1995; Bailenson, Shum, & Uttal, 2000).

Christenfeld (1995) demonstrated a very interesting contrast between the selection of common household goods and routes taken. He found that people prefer to take products from the middle two rows in a grocery shelf with four rows; enter the middle two stalls when four stalls are in a restroom; use the middle two toilet paper dispensers when four toilet paper dispensers in a stall are available; put an x in the middle circle in a row with three circles, and circle one *x* from the middle two *x*s in a row with four *x*s. However, a completely different behavior pattern is discovered during route selection, revealing that people tend to avoid the middle routes and prefer the first (first priority) or the last (second priority) among multiple choices when required to select a route from A to B on a sheet. As shown in Figure 30 at X-A, B, and C, people consistently prefer the routes that enable them to defer the turn as long as possible, regardless of the number of alternative choices. The second favorite is the route that enables them to make the turn at the very beginning. In other words, people seem to avoid taking routes other than the first or last.

feld suggests that this tic of deferring the decision might be applied to minimize mental effort, since these kinds of choices are intuitional.

Bailenson, Shum, and Uttal (2000) propose a second heuristic suggesting that people rely on the 'initial segment strategy' during route selection. As illustrated in Figure 30 at Y-A, B, and C,

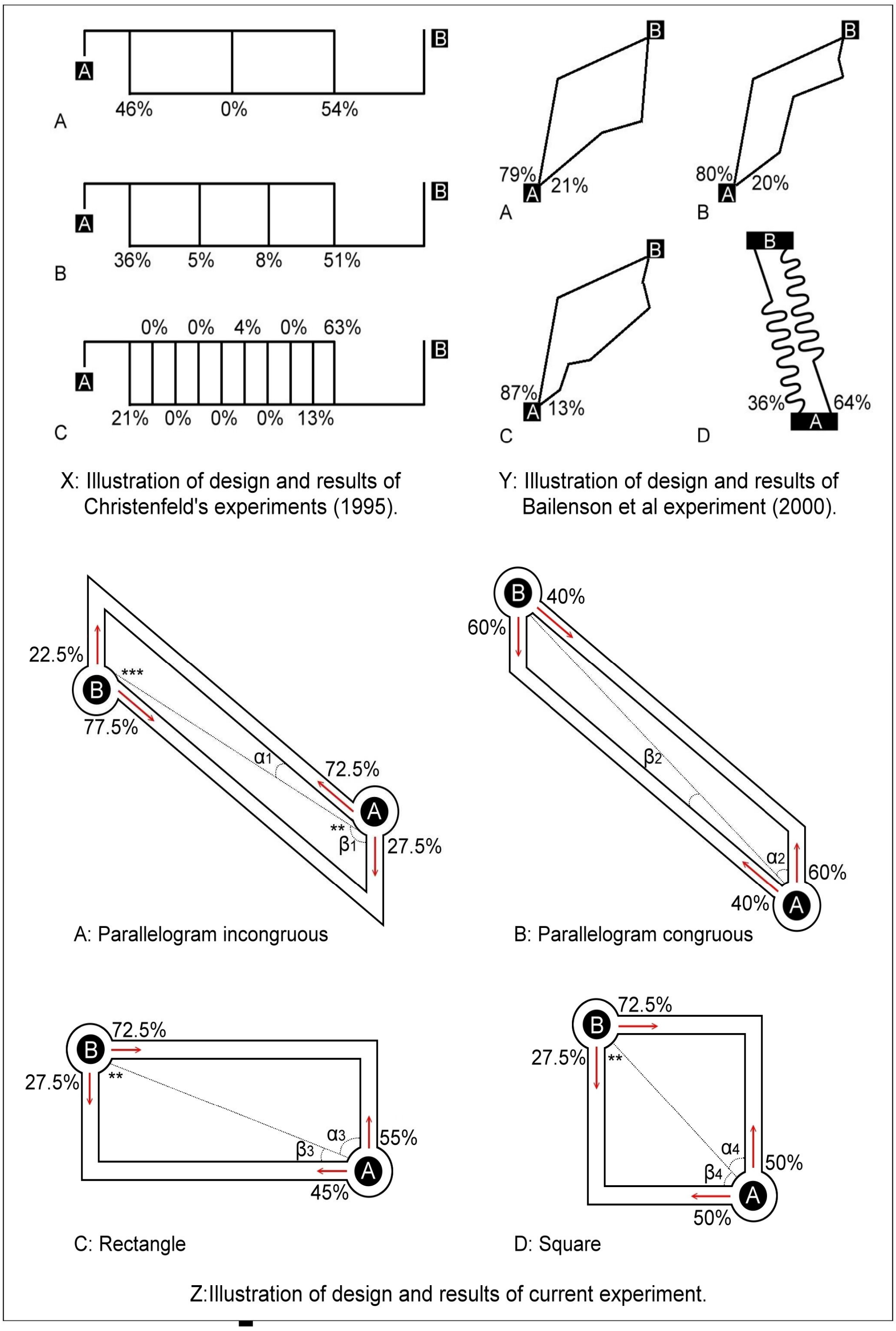


Figure 30. Illustrations of route design and results in experiments of Christenfeld (1994), Bailenson et al (2000), and current experiment. The asterisks in Z section denote the significance of Chi-square (χ2) tests between the two alternative choices (* $p \leq .05$; ** $p \leq .01$; *** $P \leq .01$)

they demonstrated that participants consistently prefer the single-turn route to multiple-turn routes during two-alternative equidistant route selection, regardless of the location of the origin. They argue that the preference stems from the straightness of the initial segments of the route; the single-turn route is straighter than the alternative choices in the initial segments. Their proposition is further confirmed in their Experiments 2 and 3. In their Experiment 2, one route is initially straight but circuitous in the rest. The alternative route is just the inverse of the previous one, being initially circuitous but straight in the rest, as shown in Figure 30 at Y-D. The results reveal that people prefer the routes which begin straight to those beginning circuitously, whether left or right. In their Experiment 3, they used the identical map but divided the maps into different regions. They demonstrated that people prefer the route which does not contain turns within the initial section. Overall, their results support their proposition that the initial straightness of the routes is critical for route selection.

However, although their results coincide with their proposed heuristic, the heuristic cannot be reconciled with the results obtained by Christenfeld (1995). If initial route straightness is important for route selection, then selection probability should systematically decrease from the final choice to the initial choice due to the systematic reduction of the initial straightness, as shown in Figure 30 at X-A, B, and C. However, instead of varying systematically from the final choice to the initial choice, the selection concentrates on the extreme (the first and the last) routes. The middle routes are rarely selected.

In this paper, I explore a third heuristic applied during route selection. I propose that humans prefer the route whose initial direction lies towards the destination, while avoiding the route whose initial direction lies away from the destination.

I speculate that the feeling of walking towards or away from the destination will influence the decision of route selection.

The new heuristic was examined by using various maps of walking situations where pathways constituted a parallelogram, a rectangle and a square, as shown in Figure 30 at Z-A, B, C, and D.

## 6.3 Experiment 10

### 6.3.1 Method

#### 6.3.1.1 Participants

A total of 320 pedestrians (181 males and 139 females) with a mean age of 25.73 (ranging from 15.9 to 61.16 years) participated in the experiment. Participants were recruited while walking across the Irchel campus of the University of Zurich and tested immediately after their consent without any reward. The Irchel campus of the University of Zurich is in a different location from the Oerlikon campus mentioned previously. Participants were required to participate in one of the eight different walking situations (described below), with 40 persons in each situation. After the short test, participants were asked about their handedness and their country of residence before age 18 (instead of their nationality). Of all those participating, 91.8 % (294 persons) reported themselves as right-handers and 8.2 % as left-handers. This ratio is comparable to previous investigation (Coren, 1992). All of the participants had resided in countries with right-side traffic regulations except one, who came from England. These included Switzerland (242 persons), Germany (33 persons), Austria (7 persons), India (4 persons), Russia, France, Italy, the Netherlands (3 persons from each country), Liechtenstein, Poland, Turkey, Taiwan, the United States (2 persons from each country), Croatia, Greece, Ireland, Norway, Serbia, Spain, Thailand, Israel, Luxembourg, Mexico, Denmark, and England (1 person from each country).

#### 6.3.1.2 Materials

Four different forked pathways were designed, as shown in Figure 30 at Z-A, B, C, and D. The pathways, presented on different maps, constituted a parallelogram (condition A and B), a rectangle (condition C), and a square (condition D). An origin (denoted as A) and a destination (denoted as B) were marked on the maps. The origin and the destination were exchanged, which generated eight different pathways (participants were still required to travel from A to B, but the location of A and B were exchanged). The different pathways were printed on an A5 paper sheet.

#### 6.3.1.3 Procedure

After consenting to participate in the experiment, participants were presented with the A5 sheet printed with one of the eight pathways. This map was presented parallel to the ground (supported by a board) and aligned with the participant’s walking direction prior to testing. Participants were instructed to select a route when traveling from an origin (denoted as A in the map) to a destination (denoted as B in the map). Participants were reminded that the alternative routes were equal in distance because the routes constitute a parallelogram, rectangle, and square in the maps. They were instructed to illustrate their decision by marking the route they would take on the map.

### 6.3.2 Results

Chi-square ($\chi 2$) tests were conducted to investigate whether there was a significant preference for either of the two alternative routes in different situations. The data of right-handers and left-handers were pooled due to there being only 26 left-handers overall. The choice frequency of the alternative routes and the Chi-square ($\chi 2$) statistics in different situations are shown in Table 2. The pattern of results remains unchanged when the data of the 26 left-handers were excluded.

Table 2. The results of Chi-square ($\chi^2$) tests in different conditions.

| | Starting | Left route[4] | Right route | Chi-square ($\chi^2$) | *P* value |
|---|---|---|---|---|---|
| A: Parallelgram incongruous | A | 11(27.5 %)[5] | 29(72.5 %) | $\chi^2(1) = 8.1$ | .004 ** |
| | B | 9(22.5 %) | 31(77.5 %) | $\chi^2(1) = 12.1$ | .001 *** |
| B: Parallelgram congruous | A | 16(40 %) | 24(60 %) | $\chi^2(1) = 1.6$ | .206 |
| | B | 16 (40 %) | 24(60 %) | $\chi^2(1) = 1.6$ | .206 |
| C: Rectangle | A | 18(45 %) | 22(55 %) | $\chi^2(1) = 0.4$ | .527 |
| | B | 29(72.5 %) | 11(27.5 %) | $\chi^2(1) = 8.1$ | .004 ** |
| D: Square | A | 20(50 %) | 20(50 %) | $\chi^2(1) = 0$ | 1 |
| | B | 29(72.5%) | 11(27.5%) | $\chi^2(1) = 8.1$ | .004 ** |

As can be seen from Table 2, a selection bias for one specific route was observed in condition A regardless of the location of the origin. In addition, the selection bias was also demonstrated in condition C and D when the origin was in the upper-left section of the maps. The preference vanished in any other walking situation.

[4] The left or right routes are defined in correspondence with the direction of the virtual situation, i.e., when people are standing in front of the starting point (A, when moving from A to B, or B, when moving from B to A).

[5] Absolute and relative (between brackets) frequencies are reported.

### 6.3.3 Discussion

This experiment examines a new heuristic applied during route selection: humans prefer the route whose initial direction lies in the direction of the destination, while avoiding the routes whose initial direction lie away from the intended destination. This design of the study also allows the examination of whether the route selection might be mediated by handedness, route angles, the deferring heuristic, and the straightness heuristic. The results show that people prefer the routes that provide an initial direction compatible with the direction of the final destination. Moreover, the current viewing perspectives of the participants also influence route selection on a map. Humans also tend to avoid the routes whose initial directions conflict with their current viewing perspective.

In condition A, when the participants choose between a pathway lying towards the intended destination and one lying away from it, they prefer the routes whose initial direction lies in the direction of the destination. Consequently, an asymmetric preference was demonstrated when participants were required to travel from the other origin. However, at least four possible factors may be involved with the asymmetric pattern: handedness (Scharine & McBeath, 2002), route angle (the routes whose initial directions lie in the direction of destination also subtend smaller angles, e.g. $\alpha 1 < \beta 1$), the deferring decision heuristic (Christenfeld, 1995), and the initial straightness heuristic (Bailenson et al, 2000). These possible confounding factors were further ruled out in conditions B, C, and D.

The reduction of preference in condition B conforms to the new heuristic because the initial direction of both possible routes lie towards the destination, but the results contradict the hypotheses of handedness, route angle, deferring heuristic, and straightness heuristic. When travelling from A, a preference fails to emerge in the upward (expected by the handedness) or leftward route (expected by the hypotheses of route angles ($\beta 2 < \alpha 2$), deferring decision heuristic, and initial straightness heuristic).

A very interesting asymmetric preference is found in conditions C and D. Participants selected the two alternative routes broadly equally when required to travel from the bottom-right sections of the maps, while they preferred the rightward route and avoid the downward routes when required to travel from the upper-left sections of the maps. Although this asymmetric preference seems unexpected, the results are not surprising. In fact, the pattern is still compatible with the new heuristic. It has been widely reported that the spatial representation derived from a map is viewpoint dependent. Humans encounter difficulties in mentally accommodating themselves to the direction of maps and, thus, are vulnerable to the misalignment of maps during way-finding (Levin, 1982; Levin, Marchon, & Hanley, 1984; Aretz & Wickens, 1992; MacEachren, 1992; Pèruch & Lapin, 1993; Warren, 1994; for a review see Lobben, 2004). Recently, Weyers, Milnik, Muller, and Pauli (2006) replicated the results of Karev (2000) indicating that people prefer the right-side seats (in reference to the screen) in a theater, but only when the screen positions are at the top or right of the maps. When the screen is positioned at the bottom of the maps, participants prefer the left-side seats (in reference to the screen on bottom of the map). This might be due to the conflict between the participant's viewpoint and the orientation of the maps; the left-side preference in reference to the screen position might actually reflect a right-side preference in the participants' current viewpoint. Similarly, the downward routes when traveling from the upper left of the map in conditions C and D also contradict the participant's current viewpoint. This choice implies that participants will be forced to walk backwards in their current viewpoint, which is intolerable and thus avoided. The comparable selection between the two alternative routes in condition C contradicts the hypotheses of handedness, route angle, deferring heuristic, and straightness heuristic. Participants did not reveal a preference even though more than 90% of them are right-handed; they did not reveal a preference for the routes with smaller route angles ($\beta 3 < \alpha 3$, Figure 30 at Z-C); they did not prefer the routes when the turn was deferred, and they did not prefer the route with a straighter initial section. The results in condition D also contradict the handedness hypothesis, since participants did not reveal a preference for the rightward route.

Overall, among the factors examined in the current research, the divergent preferences demonstrated in different walking conditions can only be explained by the newly proposed heuristic. The handedness, route angles, deferring heuristic, and straightness heuristic hypotheses are comparatively less influential on route selection under the walking conditions examined in current experiment. Apparently, the relation of the initial direction of the route to the direction of the destination is a critical factor in mediating our route selection. The preference for selecting the route whose initial direction lies towards the destination might stem from avoiding the feeling of deviating from the destination. Taking the route whose direction lies away from the direction of the destination gives the impression of walking forward but moving further away from the destination.

These findings of asymmetric walking patterns in the current study are not only interesting but also important to understanding human behavior. It has been revealed that the human brain exhibits distinct activation between navigating in familiar and unfamiliar routes in virtual-reality circumstances (Epstein, Graham, & Downing, 2003). Accordingly, the adherence to the direction of destination during walking might be a result of this activation in the human brain. In addition, visual dominance in humans when perceiving and interacting with the world might also be important. It is, therefore, worthwhile to examine whether the preference pattern would still emerge in human babies or in different species, such as rats and dogs, which are olfactory-dominated animals. Moreover, these findings are widely applicable in different domains, such as architecture, urban planning, business (estimating an optimal location to attract most pedestrians), etc. It is especially enlightening for the design of public infrastructures. Pathway designs which conflict with people's intuition might be interpreted erroneously. Thus, they might not only cause inconvenience but also lead to fatal consequences during emergency evacuation (Løvås, 1998).

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# 7 Concluding Remarks and Suggestions for Future Research

Although a great deal of effort has been devoted to the research of face recognition, its mechanism remains mysterious in many aspects. This dissertation explores the mechanism of face recognition broadly from a range of perspectives. The representation of face recognition is explored hierarchically from the perspectives of 3D visual dimensions, 2D visual dimensions, and the 1D visual dimension in order to develop a more complete understanding of how human faces are represented. In addition to the exploration of face recognition, this dissertation also examines spatial representation in the natural environment.

This dissertation can be divided into four sections. In the first section, the application and characteristics of 3D face representation is examined in two studies. In the first study, I investigate the application of 3D face representation in face recognition. Participants were required to match frontal-view faces to their silhouettes. In this situation, various 2D view-based algorithms are not applicable due to the singularity of the frontal-view faces. The results reveal that participants can readily solve the tasks when the face images retain information essential for the formation of 3D face representation. The performance substantially declined when the 3D information in the faces was eliminated. These results not only provide converging evidence to support the existence of 3D face representation, but also reveal that the essence of the representation might be different in Asian and Caucasian groups. The 3D face representation seems to be more robust in European participants than Asian participants and with European faces than with Asian faces. This result might have arisen from the different facial characteristics of the two different ethnic groups, i.e. generally, European faces have more protrusive and diagnostic 3D information than Asian faces. In the second study, the issue regarding 3D face representation is extended to the aspect of development. Child participants were recruited to examine the development of 3D face representation. The results of Study 2 show that children at about 11 years old remain inaccessible to the 3D information embedded within the faces. The results of Studies 1 and 2 draw attention to the lack of concern regarding the application of 3D representations in previous research on face recognition. It clearly reveals that, in addition to 2D view-based matching, humans also apply 3D representations when recognizing faces, and this ability may take more than a decade to become mature.

In the second section, face representation is investigated from the aspect of 2D surface representation. This issue was probed using the hallmark of face recognition i.e., the face inversion effect, FIE. The fluctuation of the FIE was scrutinized in six different ratios of configural alteration. The results show that the emergence of the FIE is not robust in any arbitrary configural alteration but is susceptible to the ratio of the alteration. These results provide enlightening and important information for face recognition research. In the domain of face recognition, the FIE has been frequently adopted to examine the underlying mechanism of face processing. However, the factors that might mediate fluctuation of the FIE have not been carefully examined. The results of Study 3 suggest that the arguments derived from the emergence of the FIE should be interpreted with caution, especially when only one ratio of the configural alteration has been applied throughout the researchs, because the emergence of the FIE might be susceptible to the ratio of configural alteration.

In the third section, face representation is explored through the singular visual dimension. A novel illusion was discovered and used to explore the distortion of distance perception in the face context. The results reveal that the distance between the centre of the two irises was underestimated in Asian faces but overestimated in Caucasian faces. This phenomenon might be due to the differences in facial characteristics between Asian and Caucasian faces, especially the relative position of the eye shapes. This result provides valuable insight into the understanding of face recognition. It implies that the difference between the processing of face images and object images can be clearly demonstrated even from the perspective of one dimension.

In the fourth section, spatial representation in the natural environment is examined. A new heuristic about the selection of walking routes was proposed and demonstrated. The result of Study 4 shows that humans prefer the route whose initial direction lies in the direction of their final destination, while avoiding the route whose initial direction does not. The adherence to the direction of destination during walking might be a result of human brain activation (Epstein, Graham, & Downing, 2003). The finding of the novel heuristic is not only interesting but also important to the understanding of human walking behaviour. Moreover, it provides important knowledge for the design of public infrastructures, especially for the construction of emergency evacuation pathways (Løvås, 1998).

Taken together, this dissertation not only enriches our understanding of how humans represent faces and the natural environment, but also provides enlightening insight for further studies. It shows that faces might not only be represented in 2D form but also in 3D form. This conclusion is essential for the domain of face recognition research, because face recognition has hardly been explored from this perspective. In addition, the custom of treating the FIE as an index for examining research data on the face recognition regime might need to be inspected carefully, because the emergence of the FIE can be influenced by the ratio of configural alteration. Moreover, the face context itself might be a factor in influencing visual perception, because the addition of it can influence humans' distance perception. Finally, in addition to the representation of face, it is demonstrated that the representation of the natural environment might influence the decision of how humans select the direction in which they progress.

In the final section, based on the conclusion, some important questions that need to be further clarified by follow-up studies are marshaled as follows.

1. Efforts should be devoted to the exploration of the development of 3D face representation. Evidence has shown that the configural processing develops slower than feature processing (Mondloch et al, 2002). However, this conclusion is drawn practically from the viewpoint of 2D face representation, because their experiment required participants to distinguish 2D face images. In Study 2, I found that children at about 11 years old remain inaccessible to the 3D information embedded within faces. Therefore, an intensive investigation of the development of 3D face representation would provide valuable information to assist our understanding of the development of face recognition.
2. Apparently, a complete face representation contains multiple levels of representation, i.e. 1D, 2D, and 3D representations. Therefore, a new model of face recognition that could properly integrate the 1D, 2D, and 3D perspectives and accommodate the results from the current experiments needs to be constructed. The relationship between different levels of face representation needs to be specified in the model. For example, is 2D face representation independent of 3D face representation, or is 3D face representation based on 2D face representation? Research of haptic recognition shows that persons being blindfolded are also able to construct a robust 3D face representation without any 2D visual input. It is particularly interesting how this 3D face representation is achieved in this condition. For normal humans, it might be reasonable to speculate that 3D face representation should be accomplished

based on the 2D face representation. However, how 2D face representation contributes to the fulfillment of 3D face representation is an important issue that awaits investigation. For example, which viewpoint of 2D face representation is critical and how many 2D face representations are indispensible for the accomplishment of 3D face representation. All these concerns should be deliberately addressed in a new model of face recognition. Empirically, research from the following two approaches can provide essential contribution for the construction of a new model of face recognition.

a) *fMRI studies.* It has been found that face stimulus can elicit extraordinary strong brain activation in the fusiform area (FFA). The FFA is consequently considered as the region which is selectively involved in the perception of faces. Interesting questions that derive from the results of current studies are:
    1) Do different levels of face representations activate distinct brain areas?
    2) Do the 1D, 2D, and 3D face representations engage diverse neurological networks?
    3) How do these different neurological networks finally integrate to accomplish a robust face representation?

   Studies from neuroimaging studies would be helpful to answer these questions.

b) *Prosopagnosia studies.* Although most humans are experts in face recognition, there is a small group of humans that suffer from severe difficulties in recognizing faces. The impairment of face recognition is called prosopagnosia. Prosopagnosia could be due to brain damage or genetic in nature. Investigations into the malfunction of face recognition have already provided information to understand the normal process of face recognition. Accordingly, the distinction between multiple face representations would benefit substantially from studies of prosopagnosia patients. Based on the results of the current experiments, future studies might need to examine whether or not the multiple face representations are mutually dissociative through scrutinizing the various symptoms demonstrated in different prosopagnosia patients. The research questions that need to be answered are:

1). Will the ability to recognize faces be improved when a face is presented as a vivid 3D image?

2). Can patients with prosopagnosia process the configural information when the ratio of configural alteration is enlarged?

3). Can the Iris Illusion embedded in faces still be demonstrated in prosopagnosia patients?

3. The findings of study 3 apparently cast doubt on the reliability of the FIE as a prevalent index. Accordingly, the arguments derived from the emergence of the FIE should be interpreted carefully, especially when only one ratio of the configural alteration was applied throughout the research. Recently, Russell, Duchaine, and Nakayama (2009) have found that the magnitude of the FIE is also mediated by the face recognition ability of individuals. People with exceptionally good face recognition ability not only perform better than normal participants, but also showed a larger FIE than the normal participants. Therefore, it is necessary to scrutinize the fluctuation of FIE in differ-

ent conditions. Future work might need to examine the susceptibility of the FIE to other methodological factors in addition to the factor of ratio of configural alteration, for example, whether the FIE is also susceptible to the experimental task (recognition, memory, or force choices), the face stimuli (full color, gray scale, or line drawing images), or the participants (gender, motivation, i.e. reward or expertise). The clarification of these questions will be fundamental issues for the domain of face recognition research in order to reexamine the hallmark of face recognition.

4. In the final study of this research, a novel heuristic was found to be critical during route selection. The validity of the novel heuristic could be enhanced by examining the generality of the heuristic. Specifically, will the heuristic remain robust when it is tested on humans with different age, writing direction (Arabian, Chinese, etc.), traffic regulation (U.K., Japan, etc.), or or sense of direction? In addition, it will also be important to examine the interaction of the novel heuristic with the other two reported heuristics, i.e. 'deferring the turn', and 'initial segment strategy.' The rivalry between these heuristics could provide important insight to determine the relative weightiness of the different heuristics.

# 8 Acknowledgements

I gratefully acknowledge my debt to my supervisor Adrian Schwaninger who not only encouraged me to pursue my doctorate in Switzerland, but also provided innumerable constructive and important advice and support for my doctoral research. I am also deeply indebted to my professor Mike Martin for his beneficial suggestions and innumerable help to my doctoral study. I also wish to thank Wolfgang Marx, Susyan Jou (Taiwan), and Chon Wen Shyi (Taiwan) for their precious advice on my Ph. D research.

In addition, I also want to show my sincere appreciations to my best Swiss friends Sébastien Fernandez & Aline Tanniger, my best French friends Jean-Charles Isner & Wioletta Pijacka, my outstanding colleagues & friends Bozana Veres-Injac, Manu Meyer, Sarah Chiller-Glaus, Stefan Michel, Saskia Steiner-Koller, Stephan Christen, Anton Bolfing, Franziska Hofer, Markus Ruh, Diana Hardmeier, Moritz Jäger, Steven Poulakos, Jonas van Essen, Mathias Neukom, Alan Wales, Martina Huber, Alexei Fischer, Yi Guo, Tobias Halbherr, Jonas Sourlier, Marc Leutenegger, Christoph Meier, Martina Elisabeth Huber, Fabio Salvalai etc., and my great neighbor and friends Augusto Cabral & Lucia Amara, Bojan Antonović, and Illya Fedotenko. The friendship greatly benefits my research and enriches my lives in Switzerland. It is a wonderful experience to work in the team of CASRA.

My research was supported by a grant awarded to me from the University of Zurich. I am deeply grateful to the University of Zurich for the financial support. Furthermore, I also want to thank Mr. and Mrs. Ho for their warming reception, useful information and great Chinese food in Switzerland. In the final, I am deeply indebted to my parents, and my sisters for their unlimited support and love.

Studying abroad is one of my dreams. I am so lucky to carry out my dream in such a beautiful city and country with so many nice people. I would like to thank all the people above once again for accompanying me during the wonderful journey of life in Switzerland.

# 9 Curriculum Vitae

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